

Application of the initial model feature of microtremor to investigate a part of the geothermal field of Jiangsu region in China

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Abstract Application of geothermal resources draws growing attention in recent years as geothermal resources are an emerging clean and renewable energy. There are tremendous geothermal resources in Jiangsu Province, which have been considered as significant contributions to regional economic development and climate variation. Controlled by tectonic structure, the spatial distribution of geothermal resources is highly uneven. Because of the complexity in terms of thermal storage background and reservoir types, successful application of geothermal resources is facing many practical difficulties such as determining the drilling location of geothermal well; thus, successful geothermal exploration is still of high risk. Firstly, geothermal resources of Jiangsu Province can be categorized into four areas; thus, geothermal reservoirs of different areas are discussed in this paper. According to the results of rock samples testing and analyzing, a geothermal reservoir physical model of Southern Jiangsu geothermal resource area has been established, which can provide an initial restriction for microtremor inversion. Two survey

points with major inversion error under “blind inversion” are recalculated as well. The results show that the initial inversion model can effectively improve the accuracy of inversion and thus benefit the sounding reservoirs. By introducing the actual initial inversion model, microtremor survey method can achieve more accurate results to provide critical information for the development of geothermal resources, which reduce the risk of successful geothermal drilling.

Keywords Geothermal resources · Geothermal reservoirs · Microtremor survey method (MSM) · Initial model · Jiangsu Province

Introduction

Terrestrial heat comes from hot metamorphosis of radioactive substances in the Earth’s interior, which reaches development and utilization standards in heat-enriched areas and intense tectonic activity areas. Geothermal resources are considered as a kind of clean and renewable energy, which is widely served as generating electricity, refrigeration, heating, breeding, hatching, geothermal drying and geothermal medical. There are large geothermal reserves in China with enormous exploring potential. Hence, the pace of geothermal development and utilization has been significantly accelerated (Li and Guan 2011; Lin et al. 2013), and presents a boom scenery (Pang et al. 2012).

Located in coastal high-heat geothermal anomaly belt of Eastern China, Jiangsu Province has good geothermal geological conditions and abundant geothermal resources, which belongs to one of the most prospective zones of geothermal resources development and utilization (Wang

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et al. 2013; Zhao 2004; Zhao and Zhuang 2005; Du et al. 2012). In this place, new generation of unconsolidated sediments is widely distributed and shallow geothermal resources are considerable (Zhao 2004; Du et al. 2012; Lin et al. 2013). However, geothermal resources of Jiangsu Province are controlled by tectonic activity and their distribution is uneven (Zhao et al. 1997). Thermal storage background is different in various structural positions, and types of reservoirs are complex and diverse.

In the early 1990s, Jiangsu Province carried out research of distribution law and prospect forecasting, preliminarily summed up features of regional geothermal field and distribution law of geothermal anomaly, and discussed controlled thermal effect of structural system. However, there were few studies about geothermal reservoirs in Jiangsu Province. Pan and Ding (2001) elaborated stratigraphy, structure and hydrogeological conditions of geothermal resources formation of southern Jiangsu Province. Qi (2002) demonstrated the thermal storage condition of Xuzhou Pantang rift basin. Qiu and Zheng (2005) studied the geothermal resources' distribution and geological condition of middle of Jiangsu Province. Niu and Liu (2009) analyzed the geothermal geological condition of Yangshan of Wuxi. Feng and Cao (2007) researched the features of structures and reservoirs property of Gaoyou. Fan et al. (2012) studied the features of reservoirs and cap rock in Rudong. In Jianhu, the main geothermal reservoir is limestone (Yang et al. 2012; Luo et al. 2015). Studying the geothermal reservoirs' systematic of the whole province can provide much critical information for different prospecting methods whose results are in accordance with geothermal resources development.

Among tremendous prospecting methods, geophysical methods play an important role in locating the well position. The main methods include gravimetric method, resistivity method, magnetometry, ground magnetic method, (magnetotelluric) MT and microtremor survey method (MSM). Currently, electrical and magnetic methods and MSM are usually used. Magnetic method is quite a useful tool for geothermal exploration because of the considerable contrast of host rocks (Bruhn et al. 2010; Oskooi et al. 2005). MT has been extensively used in geothermal studies and fields, which achieves excellent application effectiveness (Johnston et al. 1992; Spichak and Manzella 2009; Oskooi and Darijani 2014; Oskooi et al. 2016). In recent years, MSM plays an important role in geothermal resources exploration as one new geophysical method (Xu et al. 2009, 2012a, b, 2013a, b).

In this paper, geothermal reservoirs of Jiangsu Province are studied. The results provide reservoirs information for geothermal and geological conditions analysis. At the same time, excellent geothermal reservoirs analysis does benefit to geophysical exploration. Furthermore, a proper initial

model, built according to the geothermal reservoir structure, can achieve more exactly inversion result thus is crucial for a successful geothermal exploration.

Division of geothermal resources areas

Jiangsu Province locates at the Eastern China and near the Yellow Sea. The stratigraphy from the Quaternary to the Pacific has been developed. There is magmatic intrusion from Proterozoic to Cenozoic. In this province, the structure is complex. It is divided into two tectonic units by the Tancheng–Lujiang fault boundary: West side is the North China plate; the east side is the South China plate (Zhao 1990). In different areas, the stratigraphy is different to both thermal reservoirs and cap rock. This research divides firstly thermal reservoirs of entire area. It is divided into four geothermal resources zones (Fig. 1) according to the difference in geological background and geothermal geological condition. They are Xuzhou geothermal resources area (I), Suqian–Lianyungang geothermal resources area (II), middle of Jiangsu Province geothermal resources area (III) and south of Jiangsu Province geothermal resources area (IV).

Analysis of geothermal reservoirs

The geothermal system includes convection and conduction types. In most cases, two types accompany and are complementary to each other. Most convection geothermal resource spreads along the tectonic fault. This geothermal type mainly distributes in Ningzhen mountain, Laoshan mountain and the edge of Maoshan mountain, which is zonal distribution. There are a few exposed in the Tan-Lu fault zone and Donghai Tang temple of north of Jiangsu and Liyang southern mountain of south of Jiangsu. It is the important convection-type geothermal resources which are controlled by this type fault in Jiangsu Province.

Most of the conduction geothermal resources distribute in depression basins or rift basins of Mesozoic and Cenozoic, and geothermal reservoirs exist in basement rock, and structural layer is the thick geothermal cap rock. The geothermal reservoirs are mainly lamellar and have large distribution. This type of geothermal resources has large distribution, which is the main geothermal type of Jiangsu Province.

Southern Jiangsu geothermal resources areas in Xiayangzi stratigraphic area develop complete stratigraphic since Sinian. There are mainly six groups of geothermal reservoirs above 3 km. The I and II groups of geothermal reservoirs are loose sand of Neogene and poorly consolidated sandstone formation of Paleogene. The

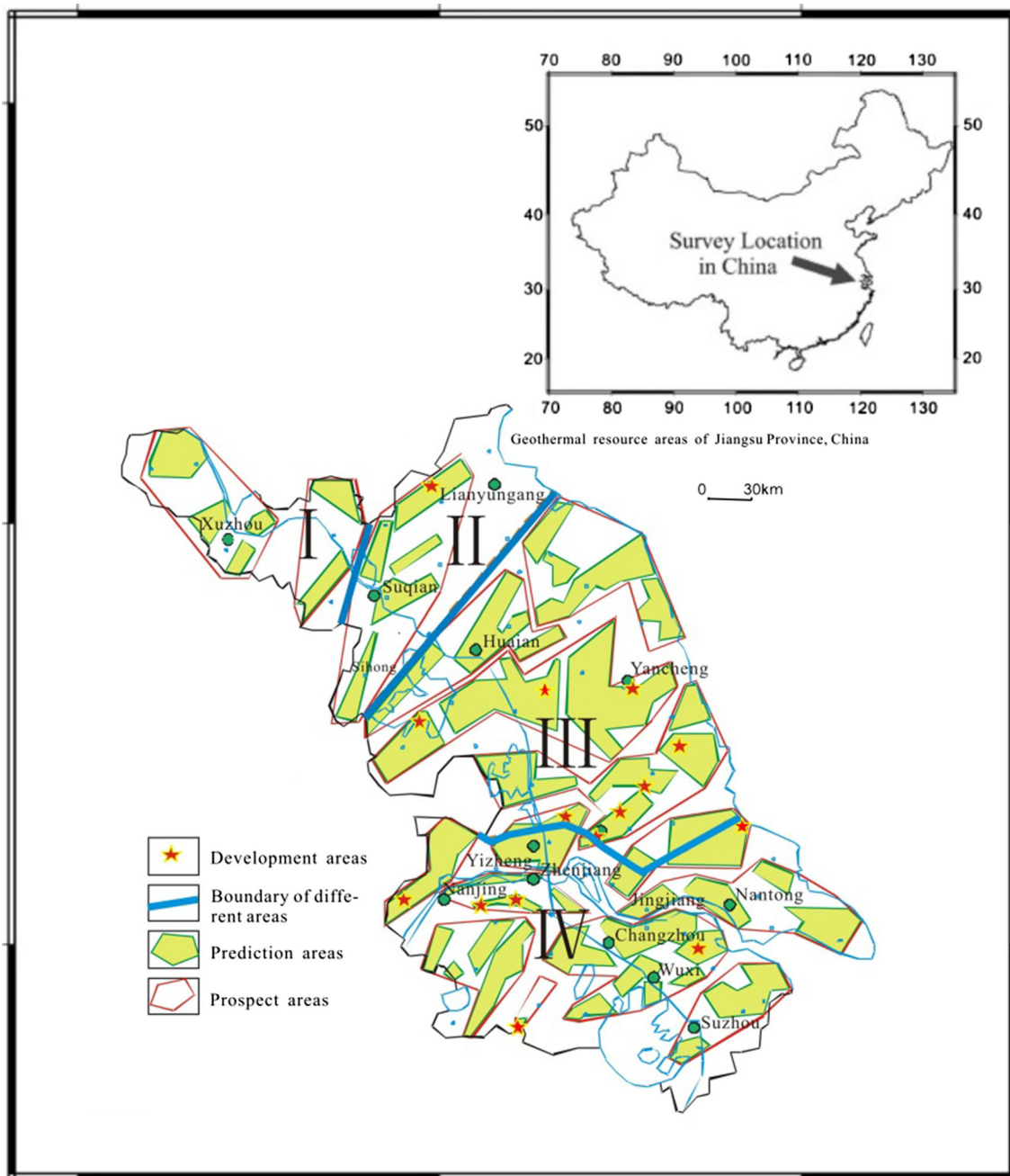


Fig. 1 Four geothermal resources areas of Jiangsu Province, China

III, IV, V and VI groups of geothermal reservoirs are Triassic which develops karst to carbonate strata of Sinian (Table 1). We elaborate in detail the six groups of geothermal reservoirs of south of Jiangsu geothermal resources areas in Xiayangzi stratigraphic area.

The I group geothermal reservoir occurs in the stratigraphic of Yancheng formation. This reservoir has high porosity, high permeability and abundant water content. Its water quality has major changes. The mineralization degree is low when it is not affected by high-

mineralization-degree water, less than 1 g/L. When it participates in deep hydrothermal circulation and is mixed by high-mineralization-degree water, it will have high mineralization degree, such as the geothermal water of Tai geothermal well 1's mineralization degree reaches 6.53 g/L (Cl-Na Type).

The II group geothermal reservoir occurs in the stratigraphic of sandstone and conglomerate of Sanduo and Dainan formation in north of Jiangsu Basin. Its water quality is generally Cl-Na type, and the mineralization

Table 1 Geothermal reservoirs of southern Jiangsu areas

Lithostratigraphic			Thickness (m)	Brief lithology	Thermal conductivity (W/m K)	Geothermal reservoir		
Period	Formation	Code						
Cenozoic	Quaternary		Q	0–312	Loam, silty sand, pebbly sand	2.37		
	Neogene	<i>Yancheng</i>	N_{1-2yc}	0–1539	Loam, fine sand, pebbly sand, local fold basalt	2.28	I (pore water)	
	Paleogene	<i>Sanduo</i>	E_{2-3s}	0–1356	Fine sandstone and silty mudstone, pebbly coarse sandstone, local fold basalt	1.51	II (pore fissure water)	
		<i>Dainan</i>	E_{2d}	0–1051	Mudstone fold gypsum, conglomerate, local fold basalt	2.36		
		<i>Funing</i>	E_{1f}	0–1605	Mudstone, limestone, fine sandstone, local fold basalt	2.30		
		<i>Taizhou</i>	E_{1t}	0–356	Mudstone, limestone, local fold basalt	2.44		
Mesozoic	Cretaceous	<i>Chishan</i>	K_{2c}	0–621	Fine sandstone, mudstone	1.51		
		<i>Pukou</i>	K_{2p}	0–1874	Mudstone, argillaceous siltstone, breccia, basaltic andesite	2.26		
		<i>Shangdang</i>	K_{1s}	0–2009	Quartz andesite, quartz trachyandesite, dacite rhyolite			
		<i>Gecun</i>	K_{1g}	0–574	Conglomerate, sandstone, mudstone, andesite	2.73		
	Jurassic	<i>Longwang mountain</i>	J_{3lw}	0–354	Andesite, trachyandesite, brecciated lava, tuff	2.21		
		<i>Xiheng mountain</i>	J_{3x}	0–444	Tuffaceous sandstone, mudstone, siltstone			
		<i>Beixiang mountain</i>	J_{2b}	0–815	Lithic sandstone, feldspar quartz sandstone, quartz sandstone			
		<i>Zhong mountain</i>	J_{1z}	0–354	Feldspar quartz sandstone, siltstone, sandstone containing pebbly and quartz			
		Triassic	<i>Fanjiatang</i>	T_{3f}	0–249	Fine sandstone containing carbonaceous mudstone, coal		
			<i>Huangmaqing</i>	T_{2h}	0–1037	Mudstone, siltstone, feldspar quartz sandstone, calcareous mudstone		
	<i>Zhouchongcun</i>		T_{2z}	0–633	Argillaceous limestone, argillaceous siltstone, limestone		III (karst fissure water)	
	<i>Qinglong</i>		T_{1q}	259–684	Limestone, nodular limestone, argillaceous limestone, mudstone	2.78		
	Upper Paleozoic	Permian	<i>Dalong</i>	P_{3d}	32–48	Shale, siliceous shale, calcareous mudstone		2.88
			<i>Longtan</i>	P_{2-3l}	14–262	Mudstone, siltstone and fine sandstone, interbedded with limestone, coal		2.49
<i>Gufeng</i>			P_{2g}	16–35	Siliceous shale, chert rock, phosphorus tuberculosis			
<i>Qixia</i>			P_{2q}	131–220	Limestone, siliceous limestone, containing chert nodules	3.1	IV (karst fissure water)	
Carboniferous		<i>Chuanshan</i>	C_{2P_1c}	40–72	Limestone	3.37		
		<i>Huanglong</i>	C_{2h}	62–96	Limestone	3.64		
		<i>Laohudong</i>	C_{1-2l}	16	Dolomite, containing chert nodules	5.5		
		<i>Hezhou</i>	C_{1h}	18	Limestone, dolomite, shale			
		<i>Gaoli, ountain</i>	C_{1g}	45	Sandstone, siltstone, shale	2.98		
		<i>Jinling</i>	C_{1j}	9	Limestone	3.32		
Devonian	<i>Leigutai</i>	D_3C_{1l}	60	Quartz sandstone, shale				
	<i>Guanshan</i>	D_{3g}	123	Quartzite sandstone, sandstone, shale	5.37			

Table 1 continued

Lithostratigraphic			Thickness (m)	Brief lithology	Thermal conductivity (W/m K)	Geothermal reservoir	
Period	Formation	Code					
Paleozoic	Silurian	Maoshan	<i>S_{2m}</i>	0–578	Quartz sandstone, siltstone, silty mudstone	4.14	
		Fentou	<i>S_{1f}</i>	88–593	Argillaceous siltstone, fine sandstone	3.3	
		Gaojiabain	<i>O₃S_{1g}</i>	307–1556	Shale, siltstone, fine sandstone, siliceous shale		
	Ordovician	Tangtou	<i>O_{3tt}</i>	20	Nodular argillaceous limestone, mudstone		
		Tangshan	<i>O_{3t}</i>	50	Tortoise limestone, argillaceous limestone		
		<i>Guniutan</i>	<i>O_{2g}</i>	12	<i>Limestone</i>		<i>V (karst fissure water)</i>
		<i>Dawan</i>	<i>O_{2d}</i>	18	<i>Shale, limestone</i>		
		<i>Honghuayuan</i>	<i>O_{1h}</i>	206	<i>Limestone, chert layer</i>		
		<i>Lunshan</i>	<i>O_{1l}</i>	99	<i>Dolomitic limestone, gray dolomite</i>	2.8	
		<i>Guanyintai</i>	<i>ε₃O_{1g}</i>	368–690	<i>Dolomite, gray dolomite, containing chert nodules and bands</i>	4.7	
	Cambrian	<i>Paotaishan</i>	<i>ε_{2P}</i>	37–460	<i>Argillaceous dolomite, dolomite, containing limestone</i>		
		Mufushan	<i>ε_{1m}</i>	137–224	Dolomitic limestone, dolomite, containing chert nodules and phosphorus		
		Hetang	<i>ε_{1ht}</i>	8–112	Siliceous shale, carbonaceous shale, sandy shale, containing phosphorus		
Neoproterozoic	Sinian	Dengying	<i>Z_{2d}</i>	99–1036	Dolomite, gray dolomite		Vikarst fissure water)
		Huangxu	<i>Z_{1h}</i>	535	Limestone, phyllitic silty mudstone		
	Nanhua	Sujiawan	<i>Nh_{2s}</i>	199	Phyllitic silty mudstone		
		Zhoulun	<i>Nh_{1z}</i>	408	Metamorphic feldspathic, sericite phyllite		
Mesoproterozoic		Pichengyan	<i>Ch_{1-2P}</i>	>480	Schist, plagioclase granulite, plagioclase amphibolite	19.2	

(Data in italics are the geothermal reservoirs)

degree is about 17 g/L. From the regional distribution analyzing, Dainan formation has smaller distribution and is limited to each recess of basin. However, Sanduo formation has wider distribution and all over most areas of basin. The I and II groups of geothermal reservoirs appear in group in the basin. The former has large amount of water, good quality but low temperature. The latter has small amount of water, high mineralization degree and high temperature.

The III group geothermal reservoir occurs in the stratigraphic of limestone of Qinglong formation of Triassic, which belongs to karst fissures aquifer. This geothermal reservoir mainly distributes in uplifts, which is supplied by the aquifers of Neogene and Quaternary, has better water quality and usually has low-salinity water.

The IV group geothermal reservoir occurs in the stratigraphic of limestone of Carboniferous and Permian, which belongs to karst fissures aquifer. This geothermal reservoir mainly distributes in uplift and has the similar water quality to the third group geothermal reservoir, usually low-salinity water.

The V and VI group geothermal reservoirs are identified in the layers of dolomitic limestone and gray dolomite in the Ordovician and Cambrian, and dolomite and limestone in the Sinian, which belong to karst fissures aquifer. The mineralization degree is different with place, about 1–3 g/L, but it reaches 24 g/L in the basin of Cenozoic. Currently, many high-yield geothermal wells in this province are found in these two geothermal reservoirs, such as the geothermal well in Laozi mountain of Hongze, Baoying, Taizhou, Jiangdu, Tang mountain of Nanjing, Tangquan.

Basic theory of MSM

In the geothermal resources survey, geophysical detection results provide much important accordance for the location of geothermal well and are critical to improve the success rate of geothermal drilling wells. Among the geophysical methods, microtremor survey method (MSM) (Aki 1957; Okada and Ling 1994; Okada 2003) has gradually become the routine method in the geothermal resource survey as one new kind of geophysical technique (Xu et al. 2009, 2012a, b, 2013a, b).

It uses the ambient noise as the signal. Then, the dispersion curve can be extracted from the signal by using spatial autocorrelation (SPAC) method (Aki 1957) or F-K method (Capon 1969); then, S wave velocity structure is achieved by inversion, which can provide the depth information of the geothermal reservoirs. Its workflow is shown in Fig. 2.

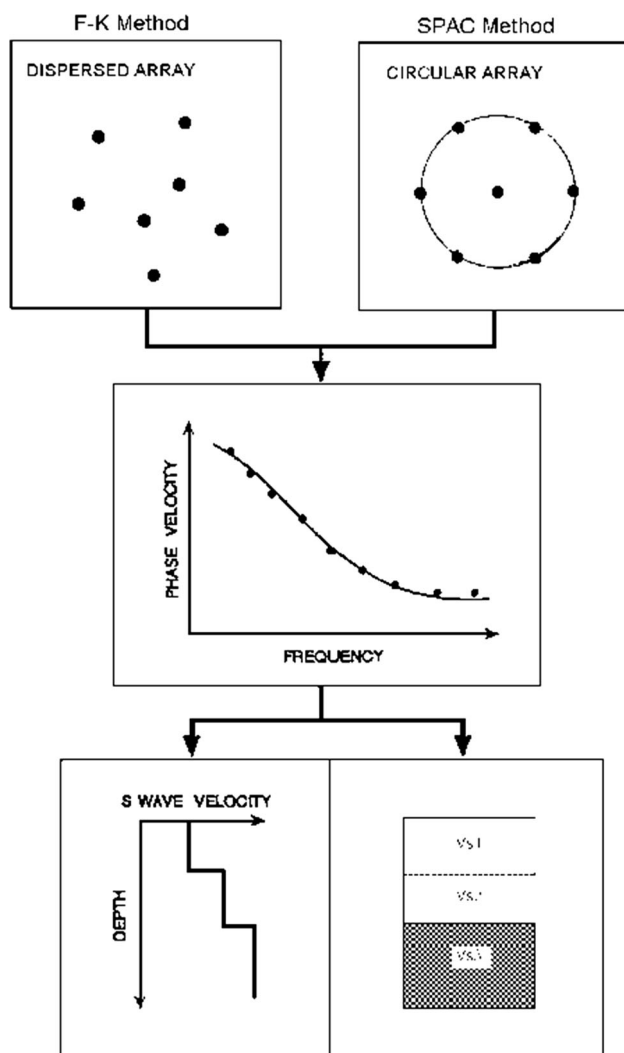


Fig. 2 Workflow of MSM

Initial inversion model of MSM

According to the research of geothermal reservoirs, the geological material of survey areas and the rock physical parameters of geothermal reservoirs, corresponding initial inversion model is built which can provide restriction to the inversion of actual dispersion curve and improve the accuracy of inversion result. By testing rock samples in laboratory, the stratigraphic physical parameters are achieved which are shown in Table 2.

In the south of Jiangsu geothermal resources area, there are six groups of geothermal reservoirs, which are karst fissure water in the layer of limestone and pore water and fracture water in the layer of sandstone. In this zone, it has complete geothermal reservoirs and cap rocks. Initial inversion mode has been built which is shown in the Table 3. Firstly, same geothermal reservoirs are divided into the same slice according to Table 2. Geothermal reservoirs are the main criteria to divide different strata. After make sure geothermal reservoirs, rock property is the second decision factor. Finally, the same age strata is regarded as one layer. Strata parameters such as density, V_p , depth are decided by the known drilling materials.

The left of Fig. 3 is the dispersion curve in theory, and the right of Fig. 3 is the S wave velocity structure of the model, which are corresponding to the initial model. From the figure, we can see that the dispersion curve trends to be linear when the frequency is above 1.3 Hz and the phase velocity is 0.6 km/s at this time which is near to the first layer's S wave velocity of the initial model (Tables 4, 5, 6, 7).

By using the initial inversion model of the south of Jiangsu Province geothermal resources area to restrict the inversion of microtremor survey, we recalculated the data and analyzed the results by comparing them with the drilling results. In this paper, we took the Yuetang of Yizheng, Shengtaiyuan of Jingjiang as examples. In Tables 4 and 6, we show the results of microtremor “blind inversion” which is achieved by inverting without initial model restriction. Usually, MSM inversion is computed with random initial model parameters which are given without any accordance (called “blind inversion”).

Figure 4 is part signal record of Yuetang. Figure 5 is the dispersion curve and S wave velocity structure of “blind inversion” at Yuetang by using recorded microseisms which are shown in Fig. 4. Figure 6 is the corresponding result by using initial inversion model.

The same as above, Shengtaiyuan of Jingjiang is chosen as another place to compare. Figure 7 is the dispersion curve and S wave velocity structure of “blind inversion” at Yuetang by using recorded microseisms. Figure 8 is the corresponding result by using initial inversion model.

Table 2 Strata physical parameters of south of Jiangsu geothermal resources area

Lithostratigraphic	Code	Brief lithology	Density (10 ³ kg/m ³)	Magnetic susceptibility (10 ⁻⁶ 4πSI)	Resistivity (Ωm)	V _p (m/s)
Quaternary	Q	Clay, fine sand, clay	2.12	55	4–0	300–1800
Tertiary	R	Mudstone, silty mudstone, fine sandstone	2.33	17–28	5–20	2050–4200
Cretaceous	K	Siltstone, sandstone, conglomerate, andesite, basalt, medium-fine grained sandstone	2.45	130–6400	29–230	4000–4700
Jurassic	J	Andesite, lava, andesite breccia, sandstone	2.57	310	40–1520	
Triassic	T	Mudstone, shale, sandstone, limestone	2.64	4–30	270–9330	
Permian	P	Thin siliceous rocks, calcareous mudstone, feldspar quartz sandstone, siliceous shale, asphaltene chert limestone	2.50	4–30	410–10,700	5000
Carboniferous	C	Dense block and spherical limestone, thick dolomite	2.71	0–16	6500–15,100	
Devonian	D	Quartz sandstone, argillaceous siltstone, sandstone containing pebble quartz	2.58	30–34	3050	
Silurian	S	Siltstone, medium-fine grained sandstone, powder-medium-fine grained sandstone, quartz sandstone, mudstone	2.58	25–40	830–2070	
Ordovician	O	Limestone, calcareous mudstone, dolomite	2.69	12–26	670–22,300	
Cambrian	Є	Limestone, dolomite, mudstone	2.75	6	5460–18,000	
Sinian	Z	Dolomite, phyllite, limestone	2.66		540–17,300	5900

Table 3 Initial model parameters of south of Jiangsu geothermal resources area

No.	Strata age	Main lithological	Density (10 ³ kg/m ³)	V _p (m/s)	V _s (m/s)	Depth of lower boundary (m)
1	Quaternary	Clay	1.99	1050	606	300±
2	<i>Neogene and Paleogene</i>	<i>Fine sandstone</i>	2.21	3125	1804	800±
3	Cretaceous	Mudstone, etc.	2.50	4000	2309	1200±
4	Jurassic	Siltstone, andesite	2.65	4700	2714	1600±
5	<i>Triassic, Permian and Carboniferous</i>	<i>Limestone, sandstone, etc.</i>	2.62	5000	2887	2200±
6	<i>Ordovician, Cambrian and Sinian</i>	<i>Dolomite</i>	2.81	5900	3406	2500±
7			2.74	6120	3500	–

(Data in italics are the target geothermal reservoirs)

Comparing between different results, we draw the conclusions that the results of microtremor survey “blind inversion” can divide the interface which has big S wave velocity difference. Under the restriction of initial inversion model, this method can exactly detect the interface which has big velocity difference such as 0.6 (km/s). Furthermore, it can divide the interface which has small velocity difference and does not have a clear boundary

resulting from rock fracture. Thus, the initial model is critical to microtremor inversion, which can reduce the error down to 10 % and the relative error under 3 % in most parts. The layered detection results and the actual stratigraphic depth are highly consistent with each other. At the same time, these results verify the effectiveness of the microtremor survey when the initial inversion model is properly provided.

Fig. 3 Dispersion curve in theory (*left*) and initial model (*right*) of south of Jiangsu geothermal resources area

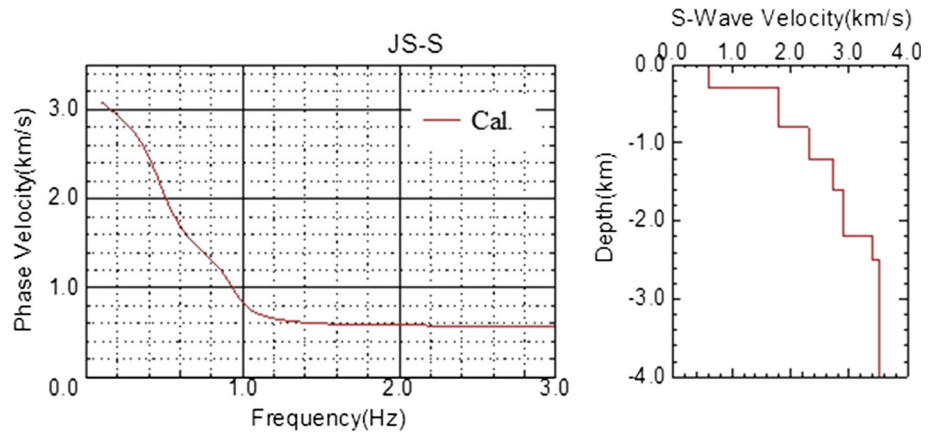


Table 4 Comparison of the result of microtremor “blind inversion” and drilling data from Yuetang of Yizheng

Stratigraphic	Lithological	Depth of lower boundary (m)	No.	V_s (km/s)	Thickness (m)	Depth of lower boundary (m)	Absolute error (m)	Relative error (%)
Quaternary	Sandy loam, clay	10						
Neogene	limestone	50						
			<i>1</i>	<i>0.910</i>	<i>105</i>	<i>105</i>		
Chishan formation of Cretaceous	Siltstone, graywacke	350	<i>2</i>	<i>1.135</i>	<i>360</i>	<i>465</i>	115	25
			<i>3</i>	<i>1.300</i>	<i>500</i>	<i>965</i>		
Pukou formation of Cretaceous	Fine sandstone	2000	<i>4</i>	<i>2.050</i>	<i>1320</i>	<i>2285</i>	285	12

(Data in italics are the result of microtremor survey method)

Table 5 Comparison of the result of microtremor re-inversion and drilling data from Yuetang of Yizheng

Stratigraphic	Lithological	Depth of lower boundary (m)	No.	V_s (km/s)	Thickness (m)	Depth of lower boundary (m)	Absolute error (m)	Relative error (%)
Quaternary	Sandy loam, clay	10						
Neogene	limestone	50	<i>1</i>	<i>0.763</i>	<i>55</i>	<i>55</i>	5	10
		350	<i>2</i>	<i>1.100</i>	<i>291</i>	<i>346</i>	4	1
Chishan formation of Cretaceous	Siltstone, graywacke		<i>3</i>	<i>1.280</i>	<i>641</i>	<i>987</i>		
			<i>4</i>	<i>1.800</i>	<i>492</i>	<i>1479</i>		
Pukou formation of Cretaceous	Fine sandstone	2000	<i>5</i>	<i>2.050</i>	<i>495</i>	<i>1974</i>	26	1

(Data in italics are the result of microtremor survey method)

Table 6 Comparison of the result of microtremor “blind inversion” and drilling data from Shengtaiyuan

Stratigraphic	Lithological	Depth of lower boundary (m)	No.	V_s (km/s)	Thickness (m)	Depth of lower boundary (m)	Absolute error (m)	Relative error (%)
Quaternary–Neogene	Clay, fine sand, coarse sand, gravel	213	<i>1</i>	<i>0.300</i>	<i>90</i>	90		
			2	<i>0.650</i>	<i>230</i>	320		
Zhouchongcun formation of Triassic	Limestone, cream mudstone, gypsum	750	3	<i>0.935</i>	<i>380</i>	700	50	7
			4	<i>1.755</i>	<i>550</i>	1250	224	18
			5	<i>2.040</i>	<i>1150</i>	2400	299	12

(Data in italics are the result of microtremor survey method)

Table 7 Comparison of the result of microtremor re-inversion and drilling data from Shengtaiyuan

Stratigraphic	Lithological	Depth of lower boundary (m)	No.	V_s (km/s)	Thickness (m)	Depth of lower boundary (m)	Absolute error (m)	Relative error (%)
Quaternary–Neogene	Clay, fine sand, coarse sand, gravel	213	<i>1</i>	<i>0.302</i>	<i>88</i>	88		
			2	<i>0.574</i>	<i>130</i>	218	5	2
Zhouchongcun formation of Triassic	Limestone, cream mudstone, gypsum	750	3	<i>0.874</i>	<i>530</i>	748	2	0.3
			4	<i>1.950</i>	<i>250</i>	998	28	3
			5	<i>2.275</i>	<i>1100</i>	2098	3	0.1

(Data in italics are the result of microtremor survey method)

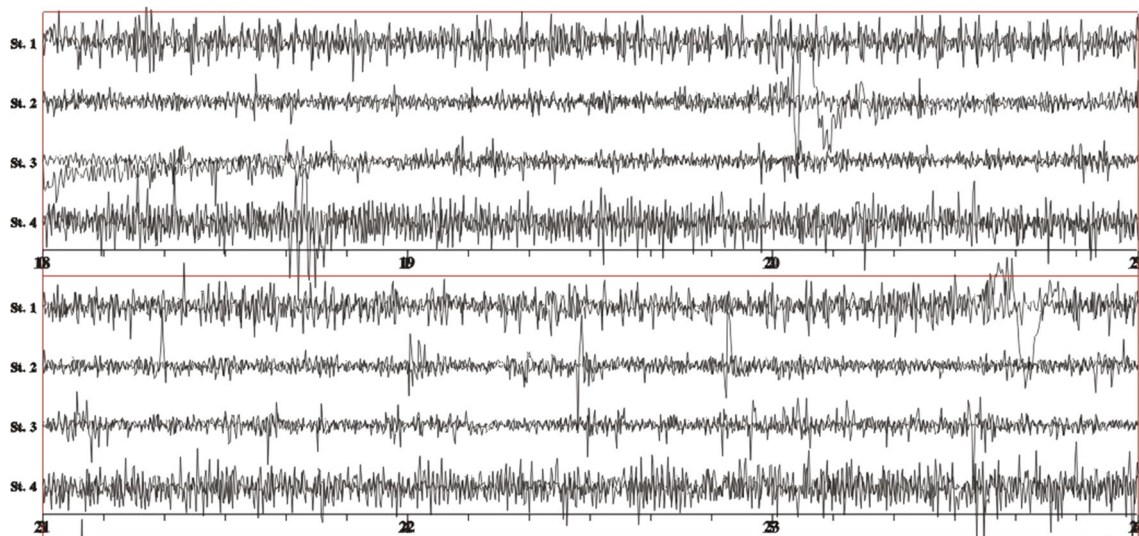


Fig. 4 An example of microtremor records at Yuetang of Yizheng

Fig. 5 Dispersion curve (*left*) and S wave velocity structure (*right*) of blind inversion in Yuetang of Yizheng

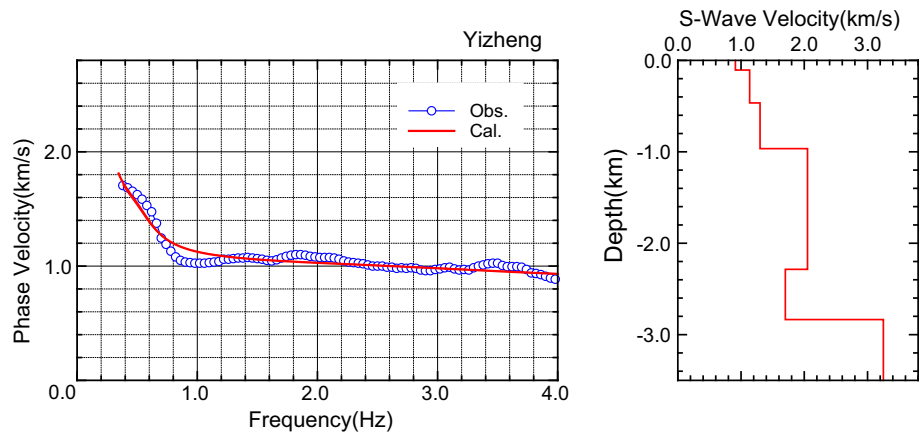


Fig. 6 Dispersion curve (*left*) and S wave velocity structure (*right*) of re-inversion in Yuetang of Yizheng

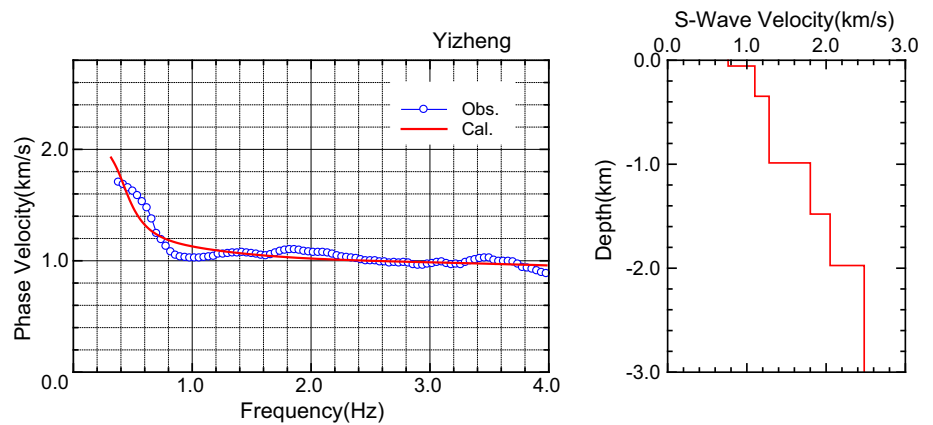
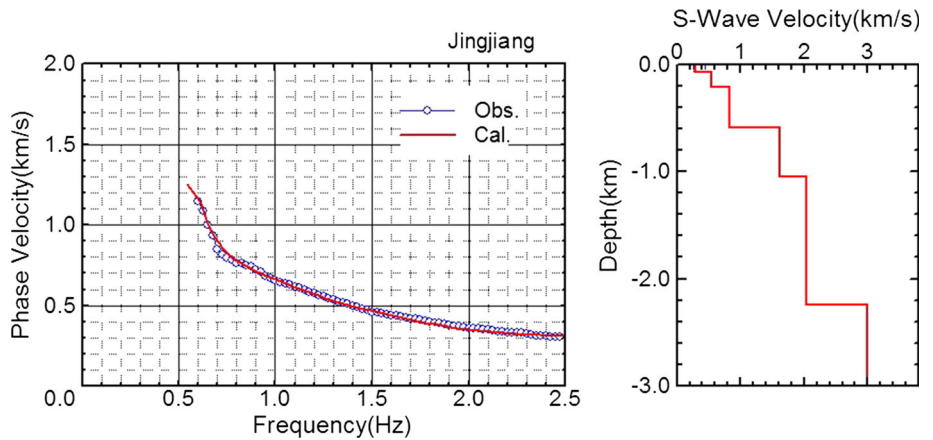


Fig. 7 Dispersion curve (*left*) and S wave velocity structure (*right*) of blind inversion in Shengtaiyuan of Jingjiang

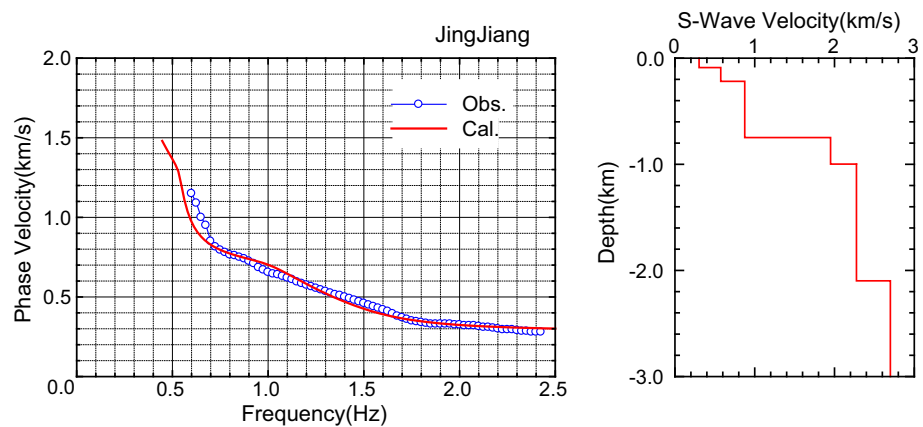


Conclusion

It is of significance for geothermal resources survey to analyze the geothermal reservoirs. In this paper, geothermal reservoirs of southern Jiangsu geothermal resources area are analyzed systematically according to the geological background and difference in geothermal geological conditions. At the same time, geothermal water types and mineralization degree are given by water samples testing.

Jiangsu Province is categorized into four geothermal resources areas. They are Xuzhou geothermal resources area, Suqian–Lianyungang geothermal resources area, middle of Jiangsu Province geothermal resources area and south of Jiangsu Province geothermal resources area. In the south of Jiangsu Province geothermal resources areas, six groups of geothermal reservoirs are developed. By testing rock samples, different physical parameters of the geothermal reservoir rock are achieved and the

Fig. 8 Dispersion curve (left) and S wave velocity structure (right) of re-inversion in Shengtaiyuan of Jingjiang



corresponding initial inversion model with six layers is been built, in which the second and sixth are geothermal reservoirs rock. Then, the worse inversion microtremor survey points are recalculated by using the initial inversion models. It provides critical information for carrying out better geothermal exploration.

MSM is one type of geophysical technique to probe the geothermal resources which has excellent effectiveness that has been verified by the actual application in Jiangsu Province. South of Jiangsu geothermal resources area is taken as an example to illustrate this method. Under the instruction of actual initial inversion model, it can achieve more accurate results to provide key information for the development of geothermal resources.

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