1 Background

1.1 Scientific Drilling—A New Field of Earth Science

The earth is a giant system including the atmosphere, hydrosphere, lithosphere, biosphere, and the mantle, core and planetary space. Earth science is the study on the substance composition, origin, formation, evolution and the interaction of each part of the earth system. In the late 20th century, the earth science developed towards the earth system science, focusing on the lithosphere, and gradually extended to the relationship and interaction with the other layers. Since the 1960s, the International Upper Mantle Program (IUMP), the Mohole Project, the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP) were successively implemented in the world, through these projects great progress was made in earth science, confirming the continental drift theory and creating the plate tectonics theory. And the international geoscience community gradually achieved a common view that scientific drilling is the only way to obtain real samples from the deep crust, and a long-term observation station can be established through scientific drilling, which is a telescope and endoscope penetrating into the earth, and is the most important technical method to research on the crustal structure and evolution. At the same time, it will play an important role in detecting the deep biosphere, explaining the mysteries of life evolution and understanding the mechanism of global environmental change. Scientific drilling is not only of important scientific significance, but also of great practical significance for maintaining the man-earth coordination and harmony, and promoting the economic and social development.

Scientific drilling is one of the important eye-catching frontier subjects of the modern earth science. According to the drilling areas, scientific drilling can be divided into ocean scientific drilling and continental scientific drilling. It is known that the world's earliest scientific drilling started from ocean. However, the continental crusts are older than oceanic crusts, with more hidden mysteries of the earth. Besides, continents are the places where human beings directly live, get the main mineral resources and suffer the greatest geological disaster threats. Therefore, people are eager to understand continents more and deeper through continental scientific drilling.

China is a large geological country, with many significant earth science problems attracting world-wide attention, such as the uplift mechanism of the third pole of the world—Qinghai-Tibet Plateau and its impact on the global environment, the formation mechanism of the Central Asia's largest fracture—Altun fracture, the cause and exhumation mechanism of the world's largest ultrahigh pressure metamorphic belt (Jiaonan-Dabie area), the focal mechanism of the Beijing-Tianjin-Hebei earthquake zone and the North China plate internal dynamics, etc. These problems urgently need the deep real information obtained through scientific drilling, especially the real samples of original cores, rocks, and fluids, etc., to reveal the mysteries and solve the key theoretical issues by using modern scientific research methods.

1.2 A Brief Introduction of China Continental Scientific Drilling Project

In the past forty years, China's geological, geophysical scientists and drilling engineers have been giving great attention and efforts to continental scientific drilling. They wrote articles and books, organized domestic and international academic exchange activities, propounded ideas, suggestions and proposals, and carried out early studies. They wholeheartedly called for the implementation of China's continental scientific drilling project and held seminars, workshops, demonstration meetings around the project's approval and initiation, feasibility study, site selection,

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construction scheme, etc., which promoted the smooth implementation of the project.

After long-term unremitting efforts, the CCSD Project was finally approved and listed as the national important scientific project in the ninth Five-Year Plan on June 4th, 1997 by the State Science and Technology Leading Group.

As one of the national important scientific projects, the CCSD Project is the deepest scientific drilling hole among the international continental scientific drilling projects currently being implemented. CCSD-1 Well is located in Maobei Village of Donghai County, Lianyungang City, Jiangsu Province, i.e. the south part of the Sulu UHP metamorphic belt.

CCSD-1 Well was officially opened on June 25th, 2001, and a grand commencement ceremony was held on August 4th, which opened a new page for China's geoscience research. After nearly four years of construction, in April, 2005, drilling, logging and other constructions were completed at drill site. Zeng Peiyan, Vice Premier of the State Council, attended the hole completion ceremony held in Donghai County and declared the victorious completion of CCSD-1 Well construction. In the future, monitoring instruments would be installed in the well and a world first-class long-term deep observation laboratory would be established.

It was such a special great science project that attracted national high attention. Premier Wen Jiabao pointed out, "The CCSD Project is a comprehensive project incorporating science and technology into one, and a multi-disciplinary and multi-field system integration. The implementation of the project will promote the development of China's earth science theory and earth exploration technology level, and is of very vital significance."

The successful completion of the CCSD Project marked that China had taken a new step from a big geo-country towards a powerful one, which would inevitably exert a certain influence on the well coordinated development of society and nature and modernization construction of the country.

1.3 Site Selection and Scientific and Technological Objectives

Sixteen ultrahigh pressure metamorphic belts have been found in the global collision orogenic belts. Located in the middle east of China, Dabie-Sulu orogenic belt, the convergent boundary between the North China plate (Sino-Korean plate) and the South China plate (Yangtze plate), contains rare ultra-high pressure metamorphic minerals such as coesite and diamond, etc.

In the Dabie-Sulu ultrahigh pressure metamorphic belt, Dabie and Sulu were once an integral whole, which were separated after Mesozoic era by the Tanlu fracture, the largest fracture in east China. Here is the world largest ultrahigh pressure metamorphic belt, which is the best place to study the deep dynamics in convergent boundary of continental plates generally acknowledged by the scientists at home and abroad. The collision orogeny of the modern continental convergent boundary is now in process in the world-famous Himalayas. However, the deep process can only be remotely sensed relying upon geophysical means, while in Dabie-Sulu area it was exposed the direct result of the deep process in geological history—the ultrahigh pressure metamorphic belt, making it the best location to study the crust-mantle movements in convergent boundary of continental plates in geological history.

Coesite is a messenger from the deep earth. Like a golden key to open the deep earth, it records the geological process of the rocks intervening into and exhuming back to the ground. The research on ultrahigh pressure metamorphic rocks and coesite has become a hot point in the current geoscience study. CCSD-1 Well was drilled at the root of continental collision orogenic belt, located in the deepest part among the scientific drilling boreholes completed in the world, which was to obtain the information of the deepest through the shortest distance. In addition, it is an ideal place to study the post-orogeny, which can provide a new method for researching the mineralization of ultra-high pressure metamorphic belt, as well as a physical basis for researching the earthquake mechanism and then providing information for earthquake prediction.

After a long-term study, it was decided that the 5,000 m deep main hole of the CCSD engineering was eventually located in Donghai County, south of the Sulu high pressure metamorphic belt, with the scientific goals as the following:

Through a complete survey and comprehensive study on all the continuous cores, liquid and gaseous samples and the in situ logging data, to set up a variety of multidisciplinary fine profiles of the 5,000 m deep well; to reconstruct the deep three-dimensional material composition, distribution and the three-dimensional structure of the convergent boundary between the north China plate and the Yangtze plate; to expound the deep fluids effects in plate convergent boundary, the interaction between the crust and the mantle, and the material circulation and rheology in the mantle; to look for the symptomatic minerals formed under the ultra deep mantle conditions and to reveal the ultra-high pressure metamorphic mineralization mechanism; to establish the geophysical theory model and interpretation standards of the crystalline rock area; to reveal the formation and exhumation models of the ultrahigh pressure metamorphic rocks and the deep dynamics mechanism of the plate convergent boundary; and to study the physical, chemical and biological functions of modern crust, to make comprehensive geophysical measurements, and to accurately monitor the modern crustal movements by taking the advantages of the special underground space shaped by the 5,000 m deep hole (without noise, less disturbance, high temperature and high pressure, and with less influence of atmospheric precipitation). The 5,000 m continental scientific deep hole would become the first long-term observation and experiment station in Asia (Zhiqin et al. 2005).

The engineering technical goals of CCSD-1 Well included:

By using the modern high and new deep drilling technologies to construct the first 5,000 m scientific deep hole at the east part of Dabie-Sulu ultrahigh pressure metamorphic belt (Donghai County, Jiangsu Province) in China, and through the implementation of this scientific drilling project, to research and develop a set of new drilling technology system suitable for hard rock deep hole adverse drilling conditions; to research and develop a new combined core drilling system; to perfect the hydro-hammer drilling technologies with Chinese characteristics; to promote the further development of drilling tools and materials manufacturing technologies and to enable China's drilling technologies come up to the advanced international level in the 1990s; and to establish a test base for geophysical logging instruments, new methods, and new technologies, and thus promote the development and application of logging technologies in the country.

1.4 Developing History of CCSD Engineering

The earliest documents introducing the situations of world scientific drilling and advocating to implement the scientific drilling project in China could be traced back to the 1970s. Over more than 30 years, the developing history of scientific drilling in China could be divided into five stages, the early stage of understanding, project argumentation and demonstration stage, project preparation stage, project implementation stage, and scientific drilling popularization and application stage.

1.4.1 Early Stage of Understanding (Before 1991)

After the introduction of the world scientific drilling information into China, the geological scientists and engineers in China had always been tracking its progress, paying close attention to its development, making data collection and information research, and thinking deeply about our orientation.

Early in 1965, Mr. Xie Jiarong, the late famous geologist in China and the chief engineer of the Ministry of Geology, pointed out in a conversazione that after World War II the geological research had been developing towards two directions: to the outer space (the launch of ERTS earth resource satellite) and to the interior earth (scientific deep drilling), making great progress in geology.

In 1978, in his article entitled *To Pay Attention to the Deep Geological Study in the Research on Basic Geological Theory and Mineralization Regularity*, Xiao Qinghui from the Intelligence Institute of Chinese Academy of Geological Sciences introduced the history, present situation, significance and achievements of the world deep geological research (including scientific drilling), pointed out the necessity and urgency to carry out deep geological research in our country and offered suggestions.

In 1979, in the Second Conference held by Exploration Engineering Professional Commission of the Geological Society of China in Beidaihe, Liu Guangzhi gave a lecture on the status and developing trend of drilling techniques and for the first time introduced the developing status and prospects of super deep drilling and deep ocean drilling in foreign countries. In 1983, his article *Super Deep Drilling and Deep Geology* was published in *Geological Review*.

In 1985 and 1986, *Deep Geological Study in Foreign Countries* and *Study on the Crust and Upper Mantle* were respectively published, in which were respectively introduced the formation, development, implementation and the achievements of some deep geology research projects in the US, the former Soviet Union, Germany, France, India, Japan and other countries as well as of international cooperation, the current situation, prospect, research approaches and methods of deep geological study, and the super deep drilling status and achievements in the former Soviet Union.

In May 1988, Prof. C. Marx, president of ITE of Clausthal University of Technology of Germany visited China. He introduced in detail the status of ocean drilling and the KTB project in Germany, further deepening our understanding of world scientific deep drilling activities and their contributions to earth sciences.

In 1988, Mr. Gu Gongxu, a famous geophysicist in China pointed out in his article entitled *Suggestion on Making a Long-term Program for Continental Scientific Drilling in the Near Future* (published in *China Science and Techonology Guide* Vol. 1, 1988) that the actual results of underground inference depending only upon surface geological, geophysical and geochemical observations had been unable to satisfy the requirements of rapid development of earth sciences. He proposed that China should make a long-term planning for scientific deep drilling and also made concrete suggestions on drilling goals, well location selection, funds channels and technical equipment.

From 1988 to 1993, with Mr. Liu Guangzhi as the chief editor, *A Series of Exploration of the Deep Continental Crust* was published, which played an important role in promoting scientific drilling in China.

In September 1990, Wang Da and Zhang Wei visited Germany to attend the Fifth International Symposium on

Observation of the Continental Crust through Drilling and the opening ceremony of KTB project, and made detailed understanding of the KTB main hole drilling equipment, tools and technical program and the latest development of world scientific deep drilling. After return, they edited the *Sidelights on the Fifth International Symposium on Observation of the Continental Crust through Drilling* and the *KTB Opening Ceremony*. In October 1990, the Ministry of Geology and Mineral Resources organized the deep drilling investigation group of 5 people to visit Germany. They got a detailed understanding of German continental scientific drilling purpose, planning, management, site selection and achievements, compiled a *Comprehensive Report on German Continental Scientific Drilling*, and put forward the proposals to carry out continental scientific drilling in China and to list the pre-study on scientific drilling in the eighth Five-Year Plan (1991–1995) of the Ministry.

1.4.2 Project Argumentation and Demonstration Stage (1991–September 1999)

During this period, the investigations, visits, conferences, lectures and other international exchange activities were widely carried out, with more definite purpose and notable results obtained.

From October 21st to November 3rd, 1991, four scientists and engineers from the Ministry of Geology and Mineral Resources visited Japan. They visited the Japan Science and Technology Agency, the Resources Development Department and the Earthquake Research Institute of the University of Tokyo, the Department of Earth Science of Shizuoka University, the Geological Survey of Industrial Technology Institute of MITI, the Comprehensive Research Institute of Resources and Environmental Technology and the Research Institute of Natural Calamity Prevention Techniques, met with forty experts and scholars, and understood the purpose, significance, hole site selection of Japanese scientific deep drilling activities, the organization of Japanese Scientific Drilling (JSD) and Japanese Super Deep Core Drilling Research Association (SDD) and their main research projects and the preliminary preparation for scientific deep drilling.

From April 7th to 10th, 1992, experts of the Ministry of Geology and Mineral Resources attended the 3rd International Symposium on Observation of the Continental Crust through Drilling held in Paris, France, where they introduced the preliminary preparation and study of China's continental scientific drilling.

From April 15th to 17th, 1992, the Ministry of Geology and Mineral Resources held in Beijing the first Seminar on China Continental Scientific Drilling (CCSD), which was a meeting linking the past and the future. More than sixty experts and professors from the scientific research institutes, colleges and universities, government agencies and industrial departments attended the seminar. More than twenty papers were exchanged in the seminar, with the contents on world scientific drilling progress and achievements, and the significance, necessity and feasibility, preliminary site selection, implementation of technical policies and procedures of CCSD. Participants agreed that the CCSD Project was of great significance and imperativeness, and scientific drilling was a system project with science and technology combined, which must be carried out step by step, from easy to difficult and from shallow to deep. On the meeting, the experts proposed thirty CCSD candidate locations. After the seminar, more than thirty drilling experts held a two-day seminar, at which drilling theory, technology, equipment and other aspects of scientific drilling were discussed, and the papers presented at the seminar were compiled into a book.

From June 18th to July 2nd, 1992, at the invitation of China Academy of Geological Exploration Technology, Doctor B.N. Khakakhaev, general manager of the Russia Science and Production Consortium of Ultra Deep Hole Drilling and Comprehensive Survey of the Interior Earth (NEDRA) and Doctor M.J. Vorozhibitov, director of the Ultra Deep Drilling Laboratory of the Geological Information System Institute visited China and gave lectures. They comprehensively introduced the drilling technology and the achievements of the scientific drilling of the former Soviet Union. Meanwhile, the two sides held talks on the cooperation and exchanges issues in the field of scientific drilling.

From June 7th to 24th, 1993, at the invitation of Mr. B.N. Khakhaev, a delegation of the Ministry of Geology and Mineral Resources visited Russia and took a comprehensive study on Russian scientific drilling activities. The delegation visited the NEDRA Superdeep Drilling and Comprehensive Investigation Institute, Russian Oil Drilling Technology Institute Perm Branch, Kungur Petroleum Machinery Factory, Ural scientific ultra deep drilling site, Russian National Geo-information Technology Research Institute, Cola ultra deep drilling site, NEDRA headquarters, Institute of High Pressure Physics, and mainly investigated the evolution and adjustment of the scientific drilling programs in Russia, site selection principles and procedures, ultra deep drilling construction technology, laboratory simulation technology and geo-information obtaining technology.

On September 2nd, 1993, the First International Continental Scientific Drilling Management Conference was held at KTB scientific ultra deep hole site in Windischeschenbach, Germany, and participants from fifteen countries including China attended the conference, at which was set up a preparatory group, which was authorized to draft the framework views on the International Continental Scientific Drilling Program (ICDP) and the proposal on operation and funding issues. Based upon this proposal, a memorandum of understanding (MOU) was prepared as the foundation for countries to accede to ICDP.

From February 26th to March 1st, 1996, the Eighth International Symposium on Observation of the Continental Crust through Drilling was held in Tsukuba Scientific Town, Tokyo. During the Symposium, the International Continental Scientific Drilling Program (ICDP) was formally established. China, Germany, and the United States of America, as the sponsor nations, signed a memorandum of understanding (MOU) on ICDP and attended a large seminar on the organization, management and future international cooperation of the program. In the same year, China formally submitted to the ICDP the project implementation proposal to construct China's first continental scientific well in Dabie-Sulu area. In ICDP SAG conference held in July 1996, China's proposal was ranked as the second among the sixteen proposals submitted. The ICDP Executive Committee decided to subsidize China to hold an international symposium on site selection for CCSD project.

On August 12th, 1996, at the invitation of Exploration Engineering Professional Commission of the Geological Society of China and China Academy of Geological Exploration Technology, a delegation from German Continental Scientific Deep Drilling Program, led by Prof. R. Emmermann, the director of German Research Center for Geosciences (GFZ, GeoForschungs Zentrum), held a seminar on German KTB drilling technology at the academic exchange center of China University of Geosciences (Beijing), where they introduced KTB results in earth sciences and drilling, logging and testing technologies to more than ninety experts and scholars from various departments of China.

In August 1996, the Ministry of Geology and Mineral Resources and GFZ signed a comprehensive development agreement in Beijing.

In January 1997, a research project of 5,000 m drilling engineering was started in order to lay down a scheme for further CCSD drilling technology, including drilling equipment, apparatus, techniques, construction procedures, and evaluation of the economic feasibility of the drilling construction. This scheme was of great significance to guide the construction of the first continental scientific well.

On June 4th, 1997, the State Science and Technology Leading Group examined and discussed the major scientific engineering projects recommended and reported by the State Planning Commission according to the evaluation results from experts, and agreed in principle that the project of China Continental Scientific Drilling and other three projects listed as the second batch of the national major science projects in the ninth Five-Year Plan. Therefore, the implementation of CCSD was started.

From August 18th to 20th, 1997, the International Seminar on China Continental Scientific Drilling Engineering in Dabie-Sulu UHP Metamorphic Belt was held in Qingdao City. The seminar was funded by ICDP, and co-sponsored by the Chinese Academy of Geological Sciences and GFZ, and more than seventy experts from Germany, the United States, France, Canada, Japan and China attended the seminar. Focusing on the scientific significance and goals to carry out the scientific drilling in Dabie-Sulu UHP metamorphic belt, the participants made a full exchange and discussion on the achievements of geological and geophysical comprehensive research in three drilling candidate areas in Qianshan, Anhui Province; Zhucheng, Shandong Province and Donghai, Jiangsu Province. Finally, it was decided that Donghai should be the first choice to implement the first scientific well in China.

In early April, 1998, the Science Advisory Group of ICDP examined and approved the formal proposal concerning the continental scientific drilling project in Dabie-Sulu UHP metamorphic belt put forward by Chinese geologists jointly with other nine experts from Germany, Canada, the United States and France. Formally approved by the Executive Committee and the Executive Council of ICDP, 1.5 millions USD would be aided to the project within 5 years from 1999.

In June 1999, the CCSD Engineering Center and the Operation Support Group (OSG) of ICDP made an exchange and discussion on the design scheme of drilling, logging, testing and analysis of CCSD project and the matters concerning cooperation, and reached extensive intentions and signed an agreement.

In August 1999, Mr. Jiang Chengsong, Vice Minister of the Ministry of Land and Resources led a delegation to visit GFZ and KTB drill site. The two sides had an extensive exchange of views on further cooperation in the field of scientific drilling.

1.4.3 Project Preparation Stage (September 1999–June 2001)

On September 27th, 1999, State Planning Commission approved the proposal on China continental scientific drilling project. To strengthen the organization and leadership of CCSD project, the Ministry of Land and Resources set up a leading group of China continental scientific drilling project and a project legal person—the CCSD Engineering Center, and established a science and technology advisory committee consisted of thirty experts and academicians. This marked that the CCSD project was officially started.

In order to understand in detail the geological structure, stratum lithology and occurrence, geothermal gradient and information required by comprehensive geophysical logging in the drilling location and its surrounding area as well as to make drilling technology tests and accumulate drilling experience, the Engineering Center successively constructed three pre-pilot holes and one drilling technology test hole near CCSD-1 Well site.

For well site selection, the Engineering Center organized all sides to carry out a large number of geological and geophysical researches and found that Maobei area of Donghai County accorded with the principle of well site selection. Strong reflecting bodies of high density, high electric resistance and high wave velocity exist at 3–4 km under the ground in this area, and locate in the deepest part of the UHP metamorphic belt, where 5 km deep drilling could penetrate through the four microlithons. At the same time, here is the part with the most moderate dip angle in the UHP metamorphic belt, where a short distance of drilling could penetrate through the multiple units. The temperature measurement showed that the geothermal gradient here was not high (about 2.5 °C/100 m), which was favourable to the implementation of drilling construction.

In Donghai area of the south Sulu UHP metamorphic belt, thorough surface geological and geophysical surveys were conducted, 1:5,000 and 1:10,000 geological mapping of the drilling target area were completed (1998–1999) and the geological structure frame of the selected well site area was ascertained. 160 km seismic reflection profile across the orogen was completed with the orogenic belt lithosphere structure profile established. Some shallow borehole cores had been collected during the 1970s and 1980s were rearranged, listed, analysed and studied, from which the valuable data of shallow underground geological structure in the drilling area were obtained. All these provided an important scientific basis for the final determination of the well site location. Multi-disciplinary researches were made in Donghai area, including researches on structural geology, petrology, mineralogy, geochemistry, isotope chronology, petrophysics and biology, and great achievements were obtained. On December 24th, 1997, the Engineering Center held the Symposium of CCSD Well Selection and forty domestic geological experts and scholars participated the symposium. Through discussion, the participants agreed that Maobei could be selected as the first target area because its conditions were better than the others.

In February 2000, the Ministry of Land and Resources submitted the Official Letter on the Feasibility Study Report of the China Continental Scientific Drilling Project to the State Planning Commission. From March 18th to 19th and from April 18th to 19th, 2000, the China International Engineering Consulting Company, authorized by the State Planning Commission, respectively evaluated the engineering part and the overall part of the Feasibility Study Report of the China Continental Scientific Drilling Project. On July 31st, 2000, the State Planning Commission assigned the Official Reply to the Feasibility Study Report of the China Continental Scientific Drilling Project, in which the report was officially approved.

In November 2000, the Preliminary Engineering Design of CCSD Project was completed. After the examination by the well-known experts and scholars, on January 3rd, 2001, the Ministry of Land and Resources submitted the Official Letter on the CCSD Project Engineering Design to the State Planning Commission, and on February 6th, 2001, submitted the Official Application Letter on Starting the CCSD Project to the State Planning Commission. Based upon the feasibility study report and the opinions from the Examination Commission of the Project Engineering Design, the State Planning Commission assigned the Official Reply to the Preliminary Engineering Design and Starting of the CCSD Project on August 2nd, 2001.

In November 2000, the Engineering Center issued the public bidding documents for drilling sub-project and five drilling companies including the No. 3 Drilling Company of Zhongyuan Petroleum Exploration Bureau, Chuandong Drilling Company of Sichuan Petroleum Administration Bureau, the No. 4. Drilling Company of Zhongyuan Petroleum Exploration Bureau, the No. 1. Drilling Engineering Company of Huabei Petroleum Administration Bureau, and Bohai Drilling Company of Shengli Petroleum Administration Bureau submitted a tender respectively. In December 2000, the Engineering Center organized an investigation group to comprehensively investigate the engineering equipment, personnel quality, construction experiences, qualifications and achievements, management and construction quotations of the five bidders. On February 27th, 2001, the Engineering Center issued the bid winning notice to the No. 3. Drilling Company of Zhongyuan Petroleum Exploration Bureau of SINOPEC. On March 6th, a signing ceremony of the drilling sub-project contract was held in the Ministry of Land and Resources.

In March 2001, the Engineering Center issued the bid winning notice for logging sub-project, and officially signed the construction contract with the Logging Company of Shengli Petroleum Administration Bureau, the winning bidder.

1.4.4 Project Implementation Stage (June 2001–April 2005)

On June 25th, 2001, the CCSD pilot hole was opened.

On August 4th, 2001, an opening ceremony was formally held at Maobei construction site, Donghai County of Jiangsu Province (Fig. 1.1).

On April 16th, 2002, core drilling in the pilot hole was completed at the depth of 2046.54 m.

On May 7th, 2002, the main hole construction was started, which experienced three stages of core drilling, reaming, sidetracking (deviation correction) drilling, sidetracking (avoidance of underground obstacle) drilling and the stages

Fig. 1.1 Opening ceremony of CCSD-1 Well

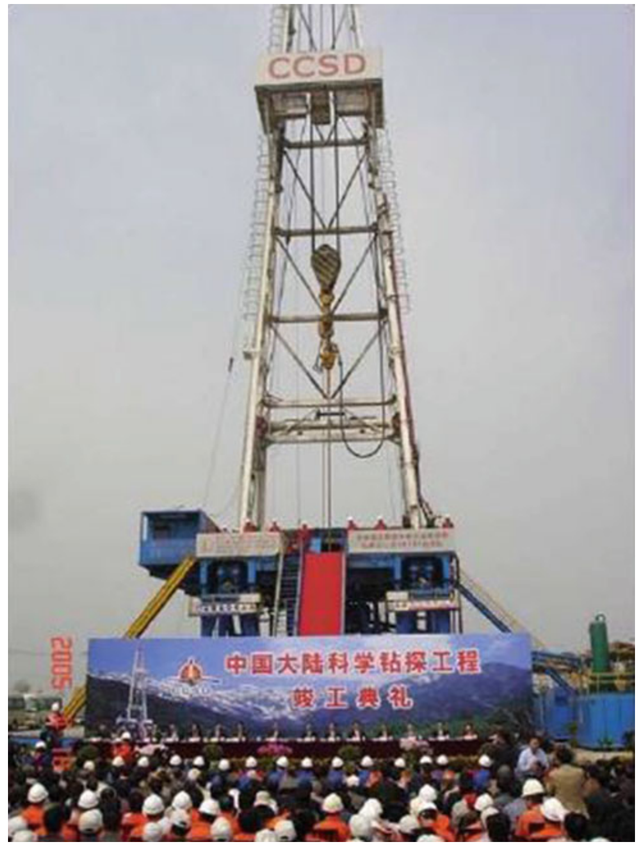


Fig. 1.2 Completion ceremony of CCSD-1 Well

of casing running and cementation, with 994 days lasted. On January 23rd, 2005, all the tasks of coring were successfully completed at the depth of 5118.2 m. After that, new drilling tools tests, liner running, cementing, drifting, logging, VSP (borehole vertical seismic profile measurement) and well completion were conducted. On April 18th, 2005, a grand completion ceremony (Fig. 1.2) was held, thus marking the completion of CCSD-1 Well (5,158 m), which totally lasted 1,395 days.

From March 30th to April 1st, 2005, the International Seminar on 10 Years Continental Scientific Drilling, Review and Prospect was held by ICDP at German Research Center for Geosciences (GFZ, Deutsches GeoForschungs Zentrum) in Potsdam, Germany and more than two hundred experts and scholars in various fields in the world attended the seminar (Fig. 1.3).

The participants widely discussed in eight fields covering climate change and global environment, meteorite impact structure, earth's biosphere and early life, volcanic system and thermal mechanism, mantle plume and rift valley, active tectonics, collision zone and convergent plate boundary and natural resources, including achievement exchange, introduction of project implementation, and plans for future research. A delegation of the CCSD project attended the seminar and showed the new development and achievements of CCSD from drilling technologies to scientific research. The successful drilling technologies and scientific significance of CCSD with a series of new achievements received high opinions from the participants.

On December 14th, 2007, the China Continental Scientific Drilling Project was checked and accepted by the State Development and Reform Commission in Beijing.

1.5 Technical Preparation

The construction of the CCSD was difficult with strict demands, requiring advanced drilling technologies and thus facing hitherto unknown challenges. To ensure the success of the construction, scientists and drilling engineers had made a large number of engineering technical preparations. To obtain foreign scientific drilling experiences in construction and management, many experts and scholars were sent abroad to study and get trained for many times, and meanwhile, some foreign experts and scholars were invited to give lectures in China. To investigate the underground geological conditions, test the drilling technology to be used in the construction and provide verification samples for

Fig. 1.3 International seminar on 10 years continental scientific drilling, review and prospect

geophysical data interpretation, a pre-pilot hole was constructed. Before and in the construction, many research projects were set, and lots of pre-studies were carried out on the construction scheme and special technologies.

1.5.1 Technical Training

In order to draw on the foreign advanced experiences and technologies in scientific drilling, in 1996, the former Ministry of Geology and Mineral Resources and the German Research Center for Geosciences (GFZ, Deutsches GeoForschungs Zentrum) signed the Memorandum of Understanding on Implementation, Administration and Operation of the International Continental Scientific Drilling Program (ICDP), in which it was specifically put forward that part of the membership dues paid by China would be used for supporting a Chinese personnel training program for a period of five years, by which the Chinese scientists and engineers would receive training at the drilling sites and accumulate experiences for the implementation of China's scientific drilling project in the future.

Since joining the international continental scientific drilling organization, China sent technical personnel to participate the continental scientific drilling training classes held by ICDP many times. In 1997, seven engineers were sent to GFZ, the headquarters of ICDP, to receive a four-month-training, mainly on drilling, logging, rock physical properties, geology, geophysics, geochemistry and information management, through which the trainees had a complete and deep understanding of scientific drilling. At the end of the course, seven trainees made a simulated design of China continental scientific drilling project, and completed a design of scientific drilling in Sulu UHP metamorphic belt.

Then, in 1998, 2000 and 2001, four to seven engineers were sent each year to GFZ to participate the ICDP training classes.

In August 1998, Ni Jialu, Yang Gansheng, Niu Yixiong and Zhang Zeming attended a continental scientific drilling engineering training held by ICDP in Hawaii, and visited the Hawaii scientific drilling site, at which they carefully investigated the purpose of scientific drilling, drilling construction methods, logging projects and methods, wellsite geologic log methods, physical parameters measurement methods and construction management, and obtained a large number of experiences concerning drilling construction management and drill site administration.

Through abovementioned technical trainings, the purpose and significance of scientific drilling were deeply understood, and the procedures and methods for conducting scientific drilling, the related technical means and technical methods, and advanced technologies and experience were obtained.

In June 1999, four experts from the Operation Support Group (OSG) of ICDP visited Beijing and carried out extensive exchanges and discussions on the design of drilling, logging, testing and analysis of the CCSD and the cooperation between the two sides.

From March to May, 2001, drilling technology training materials (two volumes) were compiled and published by the CCSD Engineering Center.

From May 23rd to 24th, 2001, the first drilling technology training class was held in the No. 3 Drilling Company of Zhongyuan Petroleum Exploration Bureau in Lankao County, Henan Province. Party A sent five experts to train the workers and technical personnel from the No. 3 Drilling Company, which was to contract for the drilling construction. More than seventy people including some leaders and drilling technicians from the Zhongyuan Petroleum Exploration Bureau, the No. 3 Drilling Company and all personnel of the 70101 Drilling Brigade attended the training class, through which the trainees got a comprehensive understanding of continental scientific drilling and the related technologies, organization and management.

From June 27th to July 3rd, 2001, the ICDP/CCSD technology training class was held. At the CCSD construction site, six experts from ICDP introduced to the engineering and technical personnel and geoscientific research personnel participating the CCSD project the field scientific planning, on-site laboratory organization, on-site geology, data management and core scanning, scientific drilling basis, KTB experience and in-the-hole test, mud and mud system, hydraulic test and fluid sampling, borehole stability in metamorphic rocks, logging basis in crystalline rocks, new development of logging techniques, and KTB/ICDP logging. Three experts from CCSD also introduced the related technologies.

1.5.2 Pre-pilot Hole Construction

To further understand the underground geological conditions of CCSD drill site and to test the drilling technologies to be used in the CCSD project, the Engineering Center entrusted Jiangsu No. 6 Geological Brigade to successively construct the Pre-pilot hole I (CCSD-PP1) in Zhimafang and the Pre-pilot hole II (CCSD-PP2) in Maobei, which mainly aimed at surveying the underground geological conditions. CCSD-PP1 was completed in November, 1997, with the hole depth of 430 m and the final hole diameter of 75 mm. Because no drilling technology test was conducted in CCSD-PP1, detailed introduction is unnecessary. Besides further survey the underground geological conditions, in CCSD-PP2 preliminary test was conducted concerning the drilling technologies to be used for the pilot hole and the main hole.

CCSD-PP2 was located in Maobei, Donghai County of Jiangsu Province, 382 m from CCSD-1 Well. The designed vertical depth was 1,000 m, with the final diameter of 75.5 mm. The engineering coordinate were: X = 3809.435 km, Y = 40378.244 km.

The drilling purposes of the CCSD-PP2 mainly included:

1. To measure the VSP (vertical seismic profile), and understand the relevant underground geological information.
2. To understand the lithology and occurrence of underground strata.
3. To make geothermal gradient and comprehensive geophysical well logging, and get strata information.
4. To test drilling technologies, methods and tools.

Strata to be drilled are mainly gneiss, interspersed with small amounts of eclogite, mixed monzonite and tectonic breccia with the following characteristics:

1. Hard to drill, with drillability grade 7–9, sometimes even to grade 10 (quartz vein).
2. Schistosity development with significant anisotropy, belonging to the strong dipping stratum; with tectonic activities such as fault.
3. With good strata integrity, and the core obtained was basically complete. Tripping was smooth, with sticking accident rarely happened.
4. Obvious fissures exist in some hole sections, resulting in complete drilling fluid loss. Slight leakage happened in most of the hole sections.

Diamond wireline core drilling method was employed for CCSD-PP2, with the main equipment and tools as follows:

1. Drill: vertical spindle hydraulic drill Type XY-6S, with 73.5 kW power
2. Derrick: Type K40 derrick, with 22 m height
3. Drill rod: S75 wireline drill rod
4. Pump: WX-200 and BW320 mud pumps were successively adopted
5. Power: diesel engine and electric generator driving methods were successively adopted
6. Drill bit: impregnated diamond core bit was mainly used for core drilling.

CCSD-PP2 hole was started on Dec. 8th, 1998, and was finished on Jun. 6th, 1999, with a total of 180 days lasted. The final hole depth reached to 1028.68 m, with the vertical depth of 1002.71 m and the final hole diameter of 75.5 mm. The total core length of the full borehole was 954.45 m, with the core recovery of 92.77 %. The hole structure and casing program had been changed during the construction, with the final hole structure shown in Fig. 1.4. In general, because the strata were relatively stable, after a small amount of casing running to isolate the overburden and the weathered layer in the upper hole section, open hole drilling was mainly conducted, and the problems of hole wall stability basically did not happen during the construction.

Two core drilling methods, conventional core drilling and wireline core drilling were employed in CCSD-PP2 hole. 75.5 mm conventional double tube diamond core drilling was adopted above 101.45 m deep, while wireline core drilling was adopted below 101.45 m. Because of the serious problems of hole deviation and drill rod broken, low drilling data were adopted when 75.5 mm diamond wireline core drilling was used, which influenced the technological and

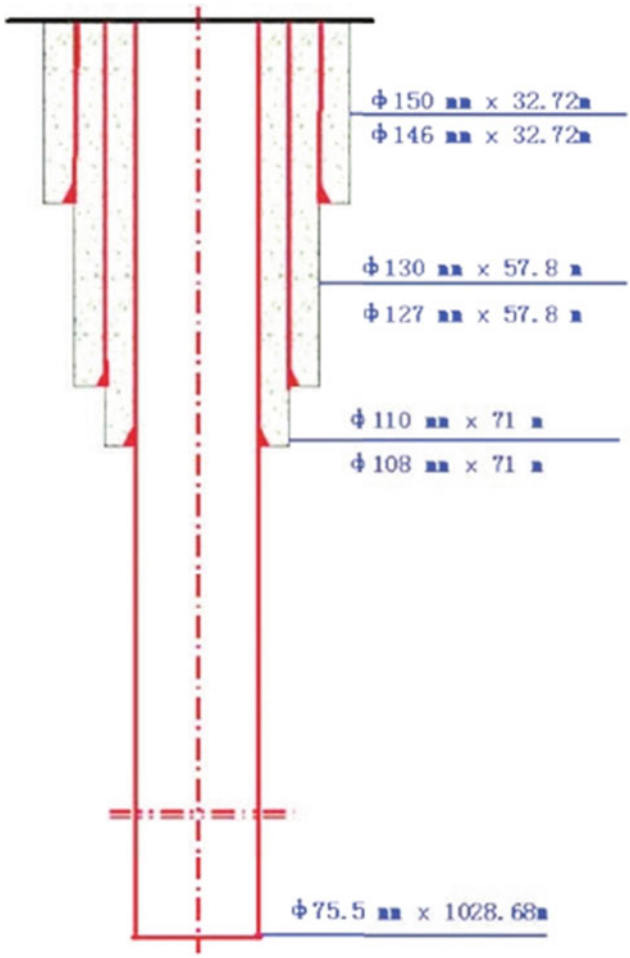


Fig. 1.4 CCSD-PP2 borehole structure

economic indexes more or less. The drilling data mainly adopted were as follows:

Bit pressure	800–1,200 kg
Rotary speed	300 r/min was mainly employed in the shallow hole section, 400 r/min occasionally employed; 200 r/min mainly employed in the deep hole section
Pumping rate	100 L/min

During drilling, the mud material LBM which was to be used in CCSD-1 Well was tried out for four times, however, without any success. The main reason was that the LBM mud could not be fully mixed due to the limited conditions and then flocculated soon once entered into circulation. Therefore, in the process of drilling, clear water added with a small amount of polyacrylamide and 126 lubricant were mainly adopted as the drilling fluid to improve its cuttings carrying capacity and lubrication effect.

Borehole deviation survey: Magnetic ball inclinometer was used to measure vertex angle and azimuth, and then hydrofluoric acid bottle inclinometer was employed to measure vertex angle after the failure of magnetic ball inclinometer.

Borehole deviation correction method: PDM/bending sub deviation correction system was utilized.

Thirty seven pieces of S75 wireline diamond core bits were used, with a total footage of 992.03 m drilled. The average bit service life was 26.81 m, while the longest was 101.4 m. The average ROP was 1.26 m/h, with the highest of 8.40 m/h. The average footage drilled per roundtrip was 1.91 m.

From June to July, 1999, hydro-hammer drilling was tested near CCSD-PP2 hole. The diameters of the hole sections penetrated with hydro-hammer were 158 mm (drilled with 158 mm non-core button impact drill bit) and 152.4 mm (drilled with 152.4 mm Type 6H637 tricone bit). The main purposes of the tests were to evaluate whether a fast drilling could be realized by using hydro-hammer in hard rocks, to understand the matching relationship between different types of drill bit and hydro-hammer, and to find out the problems of the available hydro-hammer in structure and in properties. The test results can be found in Tables 1.1 and 1.2, from which the following conclusions can be obtained.

1. Hydro-hammer drilling is an effective method for large diameter non-core drilling in hard rocks.
2. A combination of cone bit and hydro-hammer can be effectively used for large diameter non-core drilling in hard rocks.

Through drilling construction of CCSD-PP2 hole, the accurate data about the physical and mechanical properties, drillability, integrality, leakage degree, deviation degree and geothermal gradient (Fig. 1.5) of the underground strata were obtained, and temperature curves for CCSD-1 Well (Fig. 1.6) was predicted. All these provided a basis for the technical design of CCSD-1 Well.

1.5.3 Pre-research on Key Technologies

In order to make technological preparations for the implementation of the CCSD project, the Pre-research on CCSD, the research on the 5,000 m drilling engineering technical proposal and the feasibility study on the CCSD project were respectively carried out. After the official approval of the projects, the research and development of a number of key technologies were conducted in form of pre-research projects before and during the CCSD-1 Well construction.

From July 1991 to April 1994, the Chinese Academy of Geological Sciences completed the project of Pre-study on China Continental Scientific Drilling, in which a sub-project entitled the Feasibility Study on Drilling Construction

Table 1.1 Statistics of drilling rate in hydro-hammer drilling test

Hole depth (m)	Footage drilled (m)	Actual drilling time (h)	ROP (m/h)	Drilling method	Remarks
15.40–51.89	36.49	7.29	5.00	Hydro-hammer + non-core button bit	Intact and soft stratum
51.89–54.46	2.59	3.13	0.83	Hydro-hammer + non-core button bit	Hard stratum, alloy teeth seriously worn
54.46–73.59	19.47	6.53	2.98	Hydro-hammer + cone bit	Bit normal wear
73.59–75.73	1.78	1.17	1.52	Cone bit	Bit normal wear
75.73–101.14	29.05	9.97	2.91	Hydro-hammer + cone bit	Bit normal wear
Total	83.96	25.72	3.26		

Table 1.2 Comparison of drilling test results by using two types of hydro-hammer

		Footage drilled (m)		ROP (m/h)	
		KSC127	YZX127	KSC127	YZX127
Soft rocks	Button non-core bit	16.98	19.53	4.16	6.07
Hard rocks	Button non-core bit	1.16	1.41	0.95	0.74
	Cone bit	16.37	28.51	2.72	3.07
Total (based on hydro-hammer)		34.51	49.45	3.05	3.43
Total (full hole)		83.96		3.26	

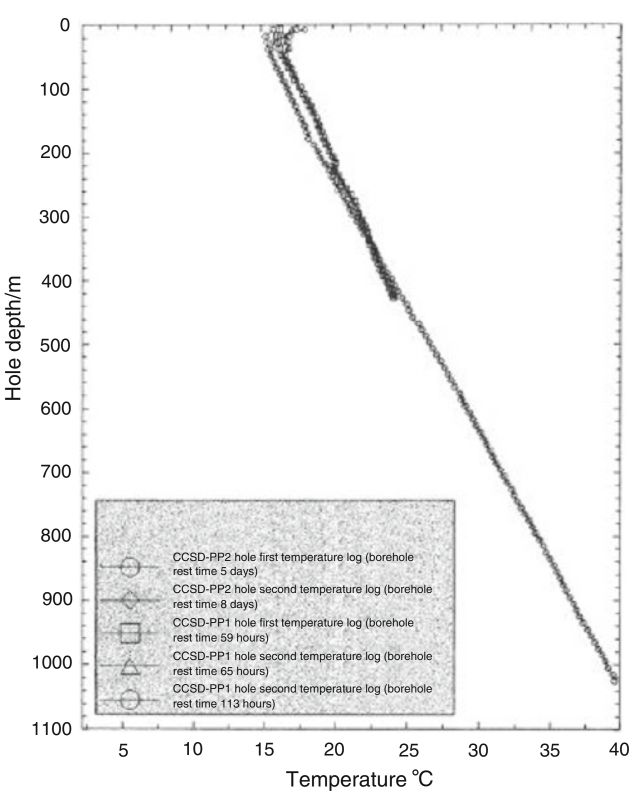


Fig. 1.5 The measured temperature curves of CCSD-PP1 and CCSD-PP2 hole

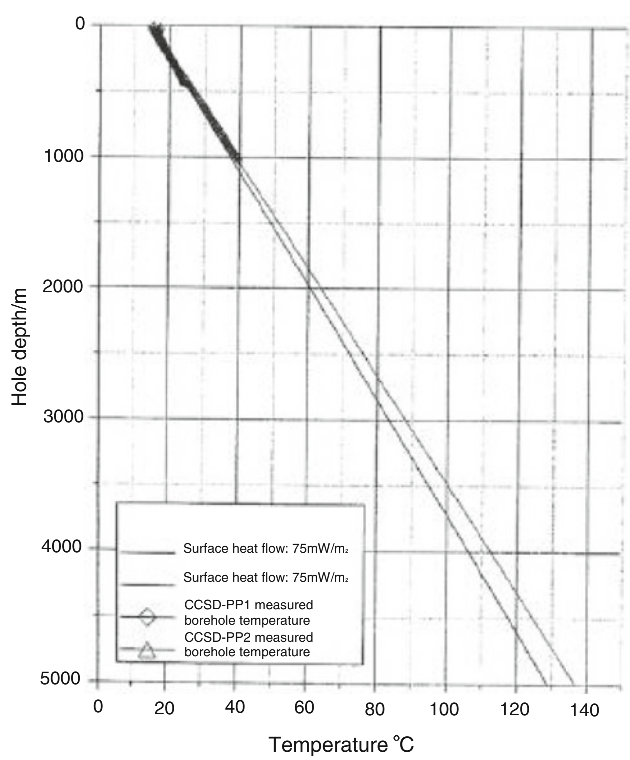
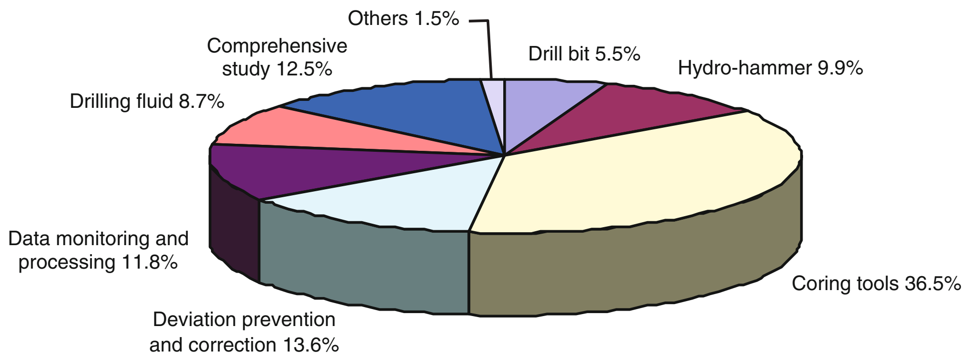


Fig. 1.6 The predicted temperature curves for CCSD-1 Well

Table 1.3 Pre-research for CCSD drilling sub-project

Category	Project	Undertaker	Checked and accepted by
	Development of 152 mm diamond wireline core drill bit (electro-plating)	Institute of Exploration Technology	China Geological Survey
Drill bit	Development of 152 mm diamond wireline core drill bit and reaming shell (heat pressing)	Beijing Institute of Exploration Engineering	China Geological Survey
	Research and development of type KZ special reaming bit for CCSD project	Institute of Exploration Techniques	CCSD Engineering Center
Hydro-hammer	Research on SYZX273 hydro-hammer	Institute of Exploration Techniques	China Geological Survey
	Development of fluidic hydro-hammer for scientific deep drilling	Jilin University	CCSD Engineering Center
Coring tools	Research on two-in-one (PDM, wireline coring) drilling tool	Institute of Exploration Techniques	CCSD Engineering Center
	Research on combined down-hole turbine motor diamond wireline core drilling tool	Institute of Exploration Techniques	CCSD Engineering Center
	Development of KS152 wireline coring hydro-percussive mechanism assembly	Institute of Exploration Techniques	CCSD Engineering Center
	Three-in-one (hydro-hammer, PDM and wireline coring) tool assembly	Institute of Exploration Techniques	China Geological Survey
	Development of KZ swivel type double tube coring tool	Institute of Exploration Techniques	CCSD Engineering Center
	Research on core orientation technology	Chengdu University of Technology	China Geological Survey
	Research on sidewall offset coring technology in CCSD project	China University of Geosciences (Beijing)	CCSD Engineering Center
Deviation prevention and correction	Research on borehole deviation prevention technology	China University of Petroleum (Beijing)	CCSD Engineering Center
	Research on PDM drive continuous deflector and its directional drilling technology	CCSD Site Headquarters, Institute of Exploration Technology	China Geological Survey
Data monitoring and processing	Development of down-hole parameters auto recording and playback device	China University of Geosciences (Wuhan)	CCSD Engineering Center
	Redevelopment of the imported drilling parameter instrument and research on site drilling database	China University of Geosciences (Wuhan)	CCSD Engineering Center
Drilling fluid	Research on the drilling fluid system for scientific drilling	Beijing Institute of Exploration Engineering	China Geological Survey
	Research on the drilling mud system for scientific drilling	China University of Petroleum (Beijing)	CCSD Engineering Center
	Research on new type formate solid-free drilling fluid	Chengdu University of Technology	CCSD Engineering Center
Comprehensive study	Research and application of new core drilling technology for deep hole in hard rocks	Beijing Institute of Exploration Engineering	CCSD Engineering Center
	Research on scientific deep hole drilling technology	Institute of Exploration Technology	CCSD Engineering Center
	Construction of experiment stand for CCSD pre-research project and test of the prototype	CCSD Site Headquarters	China Geological Survey
Others	Research on movable casing fixing and its lifting-up and running-down technology	Beijing Institute of Exploration Engineering	CCSD Engineering Center
	Research on rope arranging device for coring drawworks and its detection system	China University of Geosciences (Wuhan)	CCSD Engineering Center

Fig. 1.7 Proportion of research and development funds in pre-research of drilling sub-project



was accomplished and submitted by Zhang Wei, Geng Ruilun and Feng Qinglong of the China Academy of Geological Exploration Technology, with the main contents as follows:

1. To systematically investigate the present situation, level and developing trend of continental scientific deep drilling in the major industrial countries;
2. To put forward a variety of site selection plans for China's continental scientific deep drilling, aiming at the important basic geological problems to be resolved in the future deep geology research in our country;
3. To evaluate the present situation and level of China's deep drilling and logging techniques;
4. To expound and prove the technical (including drilling and logging) and economical feasibility of implementing continental scientific deep drilling in China, and put forward the scientific research and technological development plan;
5. To integrate the abovementioned research results, put forward the planning and related suggestions for China's continental scientific deep drilling.

During the ninth Five-Year Plan period, the research on 5,000 m drilling engineering technical proposal was officially started to extensively investigate and study the technologies needed for China's continental scientific drilling project, which included nine subjects:

1. Hole structure, drilling program and drilling technology system for 5,000 m scientific drilling construction;
2. Drilling equipment needed for 5,000 m scientific drilling;
3. Deep hole core drill string and accident handling tools, and in-the-hole core drilling system;
4. Core bit, reaming bit and reaming shell for deep hole hard rock drilling;
5. Drilling fluid and cementing slurry system for 5,000 m scientific drilling;
6. Borehole deviation prevention and correction (deflection) system for deep hole hard rock drilling;
7. Data acquisition and database system for drilling parameters in a 5,000 m scientific drilling project;
8. Core orientation method and tools for deep hole hard rock drilling;
9. Research on the information of international continental scientific drilling technology.

In 1999, the CCSD Engineering Center organized the experts in the fields of geophysical prospecting, well logging, experimental geology, drilling, drilling fluid and computer to deeply research into the feasibility of the CCSD project, and completed the Feasibility Study Report of CCSD Project.

Twenty four research and development projects concerning eight categories were carried out to solve the drilling technical problems which might be encountered during the construction of CCSD-1 Well (Table 1.3 and Fig. 1.7).