Quaternary Sediments and Paleoenvironmental Evolution in Suqian Region

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Abstract. Based on the BK2 hole of Suqian active fault detection and seismic hazard assessment project, The Quaternary comprehensive geological profile of Suqian area is analyzed and presented by the methods of lithology description, lithofacies classification, stratigraphy dating, grain size analysis and palaeospheric sporopollen sample analysis, the Quaternary Sediments and Paleoenvironmental Evolution in Suqian area are discussed. The main achievements and understandings obtained are as follows: 1. Through the grain size test and analysis, we can conclude the changes of sedimentary motivation and sedimentary environment: the sections generally experienced Qp1-2 (alluvial-diluvial of medium and high energy) → Qp2-1 zone (high-energy alluvial-diluvial) → Qp2-2 zone (middle-high energy alluvial-diluvial) → Qp2-3 zone (middle-low energy alluvial-diluvial) → Qp3-1 zone (Alluvial-diluvials→ Qp3-2 (middle and high energy alluvial-diluvials) → Qh-1 (low-lying lacustrine sediments) → Qh-2(Middle and low energy fluvial deposit). 2. According to the sporopollen map, the sporopollen assemblage of BK2 borehole since Quaternary in Suqian area was divided into 9 sporopollen assemblage zones. Based on the sporopollen assemblage, lithology and dating data, the sporopollen assemblage zone 1, II represents the last interglacial age and the last glacial age respectively; The sporopollen assemblage zones III, IV and V represent warm and dry in the early postglacial stage, warm and humid in the middle, and warm and wet in the late stage, respectively. 3. Palynological assemblages reflect the vegetation types and climate evolution during Quaternary period in Suqian city, BK2 hole of 9 Palynological assemblages corresponding to the type of vegetation and climate types: the early Pleistocene (coniferous and broad-leaved mixed forest, warm and humid), the earlier of mid-Pleistocene (coniferous-steppe, cold-dry), the mid of mid-Pleistocene (coniferous-broad-leaved mixed forest, warm and humid), the later of Middle Pleistocene (coniferous forest-steppe, warm and dry), the earlier of Late Pleistocene (coniferous and mixed forest, warm and humid), the later of Late Pleistocene (coniferous and mixed forest-grassland, cool and wet.) the early Holocene (spare deciduous broad-leaved forest - grassland, cool and dry) the mid-Holocene (spare deciduous broad-leaved forest-grassland, warm and moist, coniferous and broad-leaved mixed grassland,) the late Holocene (spare deciduous broad-leaved forest - grassland, warm and humid).
1. Introduction

Located in the north of Jiangsu Province, Suqian City belongs to cross radiation area of Huaihai economic belt, coastal economic belt and economic belt along the Yangtze River. Quaternary of Suqian area is relatively developed. Pleistocene series is most extensively distributed next to holocene series. Quaternary delocation thickness is closely related to nonuniform rise and fall of neotectonics. Seen from landform, the sediment of upwelling areas such as low mountains, hills and escarpments distributed along Tancheng-Lujing fault zone is thin while the sediment of gully depression is thick. The delocation gets thicker and thicker from west to east in the eastern plain and it’s generally 40 to 60m. Genetic type is mainly alluviation and the next ones are lacustrine sediments, limnetic sediment, alluvial and lacustrine sediments.

Suqian area has accumulated a great number of quaternary geological data since 1920. In absence of absolute dating, archaeological materials and paleontological fossils, quaternary strata can only be divided temporarily according to climatic indicators, lithological characters and geomorphic features through contrast with the strata of the neighboring area. Various units have not enough uniform genetic types and stratigraphic divisions of quaternary sediment. Liu et al and Li et al made initial division of the quaternary of Ning Town and Maoshan area respectively in 1924 and 1935. Yang and Zhou established quaternary sequence of the downstream of the Huai River in 1955. Jiangsu Geological Bureau made uniform division and contrast of quaternary in the area for the first time in 1964. Afterwards, 1:200000 regional geological survey was carried out in the whole area and quaternary sequences of low mountains and hills were established respectively. 5th Geological Team of Jiangsu Geological and Mineral Bureau made a research and division of quaternary of the downstream area of Yimu River. In recent years, Hydrogeological Team of Jiangsu Geological and Mineral Bureau, Shanghai Hydrogeological Team, Tongji University and Nanjing Institute of Geology and Palaeontology have made a research on micropaleontology, sporopollen and paleomagnetism of quaternary of the eastern plain and initially established quaternary sequence of plain area. According to Stratigraphic Guide of China (2001) and Stratigraphical Lexicon of China, Quaternary (2000), boundary of quaternary pleistocene series (Qp) and holocene series (Qh) takes the age value on boundary line of positive and reversed polarity chron and polarity subchron of magnetic strata to demarcate the ages of bottom interface of quaternary, interior upper part of pleistocene series and boundary line of holocene series. ¹⁴C dating value is used to demarcate the strata 2.5 million years ago as quaternary strata, the strata from 0.128 millions ago to 0.011 million years ago as upper formation of pleistocene series and the strata since 0.011 million years ago as the strata of holocene series.

Based on BK2 hole in the project of active fault detection and earthquake risk assessment in Suqian City, this paper adopts methods including petrographic description, lithofacies division, stratigraphic dating, analysis of ancient climate palynology samples and hole stratigraphic correlation to make a paleoenvironment and paleoclimate study on Suqian area to make a contribution to the research of paleoenvironment and paleoclimate revolution in Suqian area.

2. Basic condition of drill hole

Qualified standard drill hole location is selected according to previously existing data of quaternary strata in Suqian area and principle for selecting standard drill hole site. A representative site in the area of Liyuan Village in south central part of target area is selected in order to better grasp the developmental situation of quaternary in Suqian City. Between representative Wangzhuang-Suwei Fracture (F1) and Daguanzhuang-Shuangzhuang Fracture (F2) in this area, consideration is also given to the south side of Qianzha-Zaoho Town Fracture (F4). Quaternary of this part is completely developed, bottom margin burial depth of quaternary has large change, and bottom margin of Qp3 is about 31.8m which is a good location for implementing standard drill hole. Specific location is in the empty site at the south side of wall at the southeast side of the intersection between Development Avenue and South Huangcheng Road in the southern urban area of Suqian City. The longitude and latitude are 33°55′2.33″ and 118°16′11.96″ (see Fig. 1).
3. Chronostratigraphy test

3.1. Grain size
Laser grain size analysis on quaternary sediment of BK2 drill hole is made. MS-2000 laser grain size analyzer produced by Malvern Instruments in England is adopted in the experiment. 250 samples are selected from BK2 hole for laser grain size analysis. Strata cycle division and environmental interpretation of BK2 hole are analyzed according to feature analysis on grain size curve and grain size parameter and in combination of lithological characters of drill hole.

3.2. Sporopollen analysis
Sporopollen samples are continuously taken from quaternary sediment of quaternary BK2 standard hole (sampling depth is 1.0 to 140.5m) and there are totally 168 sporopollen samples (including relatively complete quaternary positions (i.e., Qh, Qp3, Qp2 and Qp1 positions). Pollen separation technique adopts hydrofluoric acid dissolving treatment. 5484 grains of spore pollen are authenticated from 168 samples. One sample has about 32.64 grains in average. There are rich sporopollen fossils in the upper part and one sample has about 66.9 grains in average while the lower part is short of sporopollen fossils and one sample has only 13.7 grains in average. Mean concentration of samples is 352.35 grain/g.

3.3. Dating
Systematic lithologic stratification description, systematic sampling and indoor test analysis on BK2 hole are made. Test analysis results of 466 samples in various types are obtained. 3$^{14}$C dating data, 11 OSL dating data and 9 ESR dating data are included. Sporopollen analysis is made on 168 samples and grain size analysis is made on 250 samples.

4. Result and analysis

4.1. Lithologic character
Regarding quaternary stratigraphic subdivision of BK2 drill hole in Suqian area, on one hand, the expression is that different positions (Qp1D, Qp2B, Qp3Q and QhL) have different sediment colors, lithologic markers, dating age markers, sporo-pollen assemblage markers and sediment size markers according to sedimentary evolution and climate evolution of quaternary; on the other hand, relatively more consideration is given to sediment color marker bed, lithologic marker bed, cycle and cycle bottom margin marker in position determination and overall quaternary analysis (on geochronological
subdivision, sedimentary environment and sedimentary evolution) and characters of BK2 drill hole are summarized below.

Quaternary of BK2 hole is divided into the following formations.

Lianyungang Fm of holocene series (QhL) (20.8m thick). It takes tawny artificial earth, tawny, ash black and grayish yellow clay, silty clay and argillaceous lay as majority and belongs to diluvium facies.

Upper Qizhui Fm of pleistocene series (Qp3Q) (29.8m thick). It takes brown, taupe gray, isabellinus, grayish yellow and cinerous clay and silty clay as majority and belongs to fluvial and lacustrine facies.

Medium Pogang Fm of pleistocene series (Qp2B) (62.9m thick). It takes gray, taupe, brown and maroon clay, silty clay, silt and fine sand as majority and belongs to fluvial and lacustrine facies.

Lower Douchong Fm of pleistocene series (Qp1D) (24.1m thick). It takes maroon, tawny and grayish yellow clay, silt and fine sand as majority.

Suqian Fm of pliocene series (N2S) (63.0m thick) (no bottom). The total thickness is 200.6m.

4.2. Grain size analysis

Vertical changes of grain size parameters of BK2 hole sediment are shown in Fig2. In general, commonly used grain size parameters are mode (Mo), mean grain size (Mz), standard deviation (σi), skewness (Sk) and kurtosis (Kg) (see Table 2). Each grain size parameter represents grain size characteristic of fragmentary material according to certain numerical ration and single grain size parameter and the combination feature can act as reference base for judging hydrodynamic condition of sedimentation and the sedimentary environment.

![Fig. 2 Grain-size parameters of G BK2 hole](image)

**Table 1. Qualitative description of the grain-size characteristics on the parameters**

| Standard deviation (σi)     | Skewness (Sk)       | Kurtosis (Kg)       |
|-----------------------------|---------------------|---------------------|
| excellent(<0.35)            | Very positive bias(0.30, 1.00) | very flat (<0.67)   |
| good(0.35, 0.5)             | positive bias(0.10, 0.30)     | flat(0.67, 0.9)     |
| preferably(0.5, 0.7)        | near symmetry(0.10, 0.10)    | normal distribution(0.9, 1.11) |
| secondary(0.7, 1)           | negative bias(0.30, 0.10)    | sharp(1.11, 1.56)   |
| worse(1, 2)                 | extreme negative bias(1.00, 0.30) | sharper(1.56, 3.0)  |
| poor(2, 4)                  |                     | sharpest(>3)        |
| Particularly poor(>4)       |                     |                     |
Table 2. Statistical mean value of grain-size parameters in each layer of BK2 hole

| Stratigraphic unit | Depth(m) | Sample size | Mode | Mean grain size | Standard deviation | Skewness | Kurtosis |
|--------------------|----------|-------------|------|-----------------|--------------------|----------|----------|
| Qh-2               | 0, 6.0   | 15          | 24.96| 7.19            | 1.31               | 0.76     | 3.83     |
| Qh-1               | 6.0, 20.8| 37          | 11.77| 7.85            | 1.25               | 0.44     | 3.14     |
| Qp3-2              | 20.8, 37.5| 42          | 23.08| 7.22            | 1.41               | 0.39     | 2.79     |
| Qp3-1              | 37.5, 50.6| 26          | 27.61| 7.44            | 1.36               | 0.42     | 2.63     |
| Qp2-3              | 50.6, 71.3| 42          | 14.3 | 7.71            | 1.27               | 0.36     | 2.52     |
| Qp2-2              | 71.3, 94.6| 46          | 83.32| 7.25            | 1.46               | 0.27     | 2.68     |
| Qp2-1              | 94.6, 113.5| 38          | 77.40| 7.07            | 1.55               | 0.33     | 3.14     |
| Qp1-2              | 113.5, 115.5| 4       | 122.83| 7.51          | 1.63               | -0.05    | 2.34     |

(1) Mode (Mo)

Mode refers to the grain diameter with the largest frequency distribution. Obvious grain-size change features and the law can be seen from Fig2. Mode changes are very obvious and range is relatively large from 0μm to 700μm. Mode changes along with hole depth and different lithology. 8 sections can be divided from bottom to top. Stratigraphic sedimentary dynamic and change of sedimentary environment can be comprehensively concluded. In the first cycle, mean mode of samples is 122.83μm, belong to medium and high-energy alluvial-proluvial sediment; in the second cycle, mean mode of samples is 77.4μm, indicating relatively stable high-energy alluvial-proluvial sediment; in the third cycle, mean mode of samples is 83.32μm. Medium and high-energy alluvial-proluvial sediment is major and occasionally there is sedimentary condition for fluvial sediment; in the fourth cycle, mean mode of samples is 14.3μm, roughly reflecting medium and low-energy fluvial sediment and occasional lacustrine sediment; in the fifth cycle, mean mode of samples is 27.61μm. Medium and high-energy alluvial-proluvial sediment is major and fluvial sediment is occasional; in the sixth cycle, mean mode of samples is 23.08μm, reflecting medium and high-energy alluvial-proluvial sediment; in the seventh cycle, mean mode of samples is 11.77μm, entirely reflecting low-energy lacustrine sediment; in the eighth cycle, mean mode of samples is 24.96μm, indicating relatively stable medium and low-energy fluvial sediment and occasional lacustrine sediment.

(2) Mean grain size (Mz)

Mean grain size (Mz) is the mean value of central tendency and trend about size distribution of a sample (mean grain size). Depending on the type and property of provenance to some extent and reflecting mean kinetic energy of transportation medium, it is the most important grain-size characteristic of sediment and frequently used as sedimentary rhythm and hydrodynamic energy variation curve. Among BK2 samples, mean grain size is between 2.97Φ and 8.57Φ and most grain sizes are between 4Φ and 8Φ. Fine sand, silt, silty clay and clay are main lithology characters.

(3) Standard deviation (σi)

According to different degrees of sorting, σi values are divided into 7 sorting levels (see Table 1). Among BK2 hole samples, most σi values are between 1 and 2 (237 samples) and secondly between 2 and 3 (12 samples). Seen from Table 2, mean σi value is between 1 and 2, indicating that sorted behavior of sediment in this area is relatively poor as a whole and sediment belongs to fluvial facies.

(4) Skewness (Sk)

Skewness is a parameter used to measure the symmetry of frequency curve. According to SK value sizes, SK values are divided into 5 levels (see Table 1). SK values of 7 BK2 hole samples are between -1.00 and 0.30; SK values of 8 BK2 hole samples are between -0.30 and 0.10; SK values of 18 BK2 hole samples are between -0.10 and 0.10; SK values of 72 BK2 hole samples are between 0.10 and 0.30; SK values of 130 BK2 hole samples are between 0.30 and 1.00; SK values of 15 BK2 hole samples are larger than 1. Seen from Table 2, Mean value of BK2 hole samples is between -0.05 and...
0.76. Thus, it is observed that most samples show negative bias and extreme negative bias. Sediment grain with large size is in the ascendant and belongs to fluvial facies.

(5) Kurtosis (Kg)

Hierarchical distinctions of kurtosis are shown in Table 1. Kg values of 220 BK2 hole samples are between 1.56 and 3.0 and Kg values of 28 BK2 hole samples are larger than 3.0; seen from Table 2, mean value of hole kurtosis is between 2.34 and 3.83. Thus, it is observed that most samples have narrow-deviation kurtosis, indicating that sediment belongs to belongs to fluvial facies after relatively strong transformation.

To sum up, each interval of the section generally goes through Qp1-2 interval (medium and high-energy alluvial-prolouval sediment), Qp2-1 interval (high-energy alluvial-prolouval sediment), Qp2-2 interval (medium and high-energy alluvial-prolouval sediment), Qp2-3 interval (medium and low-energy alluvial-prolouval sediment), Qp3-1 interval (medium-energy alluvial-prolouval sediment), Qp3-2 interval (medium and high-energy alluvial-prolouval sediment), Qh-1 interval (low-energy lacustrine sediment) and Qh-2 interval (medium and low-energy fluvial sediment) successively.

4.3. Sporopollen assemblage characteristics

Identification and statistics of 168 sporopollen samples selected from 140.5m above the upper part of BK2 hole section are made and 71 palynomorphs are obtained. Palynological assemblage is close to woody plant pollen and herbaceous pollen and mean contents are 49.94% and 46.73% respectively; Ferns have fewer spores whose mean content is 3.33%; sometimes there is a few of aquatic plant pollen, pediastrium and algae cysts. There are 8 woody plant species, 30 herbaceous species and 8 fern species (see Table 3). BK2 hole can be divided into 9 palynological assemblage zones (See Fig3 and Table 4) through analytical investigation and features of each zone are briefly stated below.

Palynological assemblage zone I: woody plant pollen is the dominant sporopollen in this section and herbaceous content is secondary. On the whole, vegetational assemblage takes pinus-quercus-artemisia as principle, reflecting vegetational form of theropencedrymion and entirely warm and relatively humid climate.

Palynological assemblage zone II: woody plant pollen is the dominant sporopollen in this section and herbaceous content is secondary. On the whole, vegetational assemblage takes pinus-artemisia-chenopodiaceae as principle, reflecting relatively cold and dry climate.

Palynological assemblage zone III: woody plant pollen is the dominant sporopollen in this section and herbaceous content is secondary. On the whole, vegetational assemblage takes pinus-artemisia-chenopodiaceae as principle, reflecting warm and humid climate.

Palynological assemblage zone IV: woody plant pollen is the dominant sporopollen in this section and herbaceous content is secondary. On the whole, vegetational assemblage takes pinus- artemisia-chenopodiaceae as principle, reflecting cool warm and relatively dry climate.

Palynological assemblage zone V: woody plant pollen is the dominant sporopollen in this section and herbaceous content is secondary. On the whole, vegetational assemblage takes pinus-quercus-artemisia as principle, reflecting warm and humid climate.

Palynological assemblage zone VI: woody plant pollen is the dominant sporopollen in this section and herbaceous content is secondary. On the whole, vegetational assemblage takes pinus-artemisia-chenopodiaceae as principle, reflecting cold and dry climate.

Palynological assemblage zone VII: herbaceous pollen is the dominant sporopollen in this section and has rich content. On the whole, vegetational assemblage takes artemisia- chenopodiaceae- pinus- quercus as principle, reflecting cool-warm and humid climate.

Palynological assemblage zone VIII: herbaceous pollen is the dominant sporopollen in this section and has rich content. On the whole, vegetational assemblage takes artemisia-chenopodiaceae-pinus as principle, reflecting relatively warm and humid climate.

Palynological assemblage zone IX: herbaceous pollen is the dominant sporopollen in this section and has rich content. On the whole, vegetational assemblage takes rhus-artemisia-chenopodiaceae-
pinus-quercus as principle. Climate change is relatively cool and dry on the whole and climate at the bottom is relatively cool-warm and dry.

![Pollen spectrum and Palynological assemblage in the Quaternary of BK2 hole](image)

**Fig. 3** Pollen spectrum and Palynological assemblage in the Quaternary of BK2 hole

**Table 3. Pollen types from drill hole BK2**

| Type         | Species                                                                 |
|--------------|--------------------------------------------------------------------------|
| Woody plants | Pinus, Quercus, Moraceae, Rhus, Betula/Carpinus, Osmunthus, Juglan, Hippohae, Picea, Elaeagnus |
| Herbaceous   | Gramineae, Artemisia, Chenopodiaceae, anunculaceae, Taraxacum, Liliaceae, Cyperaceae, Typh, Myriophyllum |
| Fern         | Selaginellasinensis, Lycopodium, Polypodiaceae, Adiantum/Microlepria, Monolete spores, Trilete spores |

**Table 4. Vegetation form and climate type from drill hole BK2**

| Stratigraphic unit | Sporopollen belt | Sporopollen belt depth | Vegetation form                  | Climate type         |
|--------------------|------------------|------------------------|----------------------------------|----------------------|
| Qh                 | IX               | 0m-6.0m                | Mixed Broadleaf -conifer Forest  | Cool and dry         |
| Qh                 | VIII             | 6.0m-15.8m             | Grassland                        | Warm and humid       |
| Qh                 | VII              | 15.8m-20.8m            | Mixed Broadleaf -conifer Forest –Grassland | Cool and wet.       |
| Qp3                | VI               | 20.8m-27m              | Grassland                        | Cold and dry         |
| Qp3                | V                | 27m-50.6m              | Mixed Broadleaf-conifer Forest    | warm and wet         |
| Qp2                | IV               | 50.6m-71.3m            | Grassland                        | Cool and dry         |
| Qp2                | III              | 71.3m-94.2m            | Mixed Broadleaf-conifer Forest    | warm and wet         |
| Qp2                | II               | 94.2m-113.5m           | Grassland                        | Cold and dry         |
| Qp1                | I                | 113.5m-137.6m          | Mixed Broadleaf-conifer Forest    | Warm and humid       |
4.4. Dating result
Reliability analysis on 21 data including 3 $^{14}$C dating data, 11 OSL dating data and 8 SER dating data of BK2 hole is made and good results are obtained.

![Fig. 4 Coordinated Analysis Diagram of the Reliability of BK2 Hole Dating Data](image)

Several things can be seen from Fig 3. The first is that more than 10 $^{14}$C and OSL dating data in Qp2 upper part, Qp3 and Qh positions show linear distribution and the boundary between Qh and Qp3 and the boundary between Qp3 and Qp2 are well controlled; the second is that nearly 10 data especially ESR dating data below Qp2 middle part show another set of linear distribution and the boundary between Qp2 and Qp1 and the boundary between Qp1 and N2 are well controlled; the third is that age values of samples, quaternary subdivision criterion, depth of samples and determined quaternary subdivision of drill hole within the research area show basic coordination relationship. At the same time, the unconformity between inversion to the old and skip to the new for 21 dating data of BK2 hole is not obviously shown and deposition rate is relatively uniform, which entirely states that linear distribution and harmony of age values are good and reliability is relatively high.

5. Conclusion
1. Stratigraphic sedimentary dynamic and change of sedimentary environment can be comprehensively concluded through grain size test and analysis that each interval of the section generally goes through Qp1-2 interval (medium and high-energy alluvial-proluvial sediment), Qp2-1 interval (high-energy alluvial-proluvial sediment), Qp2-2 interval (medium and high-energy alluvial-proluvial sediment), Qp2-3 interval (medium and low-energy alluvial-proluvial sediment), Qp3-1 interval (medium-energy alluvial-proluvial sediment), Qp3-2 interval (medium and high-energy alluvial-proluvial sediment), Qh-1 interval (low-energy lacustrine sediment) and Qh-2 interval (medium and low-energy fluvial sediment) successively.

2. Palynological assemblage of BK2 standard drill hole since the quaternary period is divided into 9 palynological assemblage zones according to palynogram and else. According to palynological assemblage, lithology and dating data, it is determined that palynological assemblage zone I and palynological assemblage zone II represent the last interglacial period and the last glacial period respectively; palynological assemblage zone III, palynological assemblage zone IV and palynological assemblage zone V represent the early stage of post glacial period with cool-warm and relatively dry climate, the medium stage of post glacial period with warm and humid climate and the late stage of post glacial period with cool-warm and relatively humid climate.

3. Palynological assemblage reflects the vegetational form and climate evolution of the quaternary in Suqian City. Corresponding vegetational forms and climate types of 9 palynological assemblages in
the quaternary of BK2 hole are early pleistocene (theropencedrymion, warm and humid), early stage of middle pleistocene (coniferous forest-grassland, cold and dry), middle stage of middle pleistocene (theropencedrymion, warm and humid), late stage of middle pleistocene (coniferous forest-grassland, cool-warm and relatively dry), early stage of pleistocene (coniferous and broad leaf forest, warm and humid), late stage of pleistocene (coniferous and broad leaf forest-grassland, cold and relatively humid), early stage of holocene (sparse deciduous broad-leaved forest-grassland, cool-warm and relatively dry), middle stage of holocene sparse deciduous broad-leaved forest-grassland, warm and humid) and late stage of holocene (sparse deciduous broad-leaved forest-grassland, cool-warm and relatively humid).

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