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Several Problems on Application of SEM Image in the Structure Properties Study of Loess

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Abstract: SEM microstructure images of loess, used properly, can be important means for the explanation of soil mechanics properties of loess. In this paper, the proper selection to SEM microstructure images under different studing purpose is discussed. It is also believed that the fabric of loess has a "scale effect", which makes the fabrics revealed with different magnification times for image and so does their physical substantiality. The authors define the classification of loess fabric to avoid the uncertainty in description the nature of the fabrics at different scale due to the using of the generalized term "microstructure". For the convenience of soil mechanics study, the authors also propose a new classification of pores to reflect the reality of pores, to reflect nature of their formation mechanism and their relationship with the classification of grains. Finally, some general ideas on selection of SEM images in study are summarized.

Key words: **Loess**; **Microstructure**; **SEM image**; **Pore classification**

电镜图像在黄土结构性研究中应用的几个问题

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摘　要：电镜结构性图像是认识黄土结构特征，分析黄土土力学特性的重要方法。本文对不同研究目的情况下如何利用黄土电镜微结构图像的问题进行了探讨，并指出随着观察放大倍数的不同，黄土的结构性图像显示出明显的尺度效应。定义了黄土结构性的分类以避免因笼统使用“微结构”这一词所带来的指代不准确性。根据土力学研究的需要对黄土孔隙划分标准提出了新的认识，建立一套新的分类标准以便利于研究运用。最后综述了在研究中选用黄土电镜结构性图像的原则。

关键词：黄土；微结构；电镜图像；孔隙分类

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0 Introduction

If the specific connotation of soil mechanics is not taken into consideration, the study on microstructure of soil commenced at 19th century in the field of agrology when scientist began to use optical microscope to explore the microstructure of soil. But in a sense of Soil Mechanics, the study of soil structure is rather later than that period. The masterpiece of Karl Terzaghi "Fundamentals of Soil Mechanics" published in the 1925 marked the

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birth of modern Soil Mechanics. But even in this classic work, although it was mentioned, there is not real study on the microstructure of soil from the point view of Soil Mechanics. Substantial progress started in this field only after the widely use of Electronic Microscopes in 1950's. At the same time, the classic Soil Mechanics, which is based on Continum Mechanics, confronted some difficulties. For example, the substantial gap between the theoretical calculation and the observation in practice in some cases, the non-linear behavior and structure characteristics of soil, all that cannot be solved well using the classic Soil Mechanics methods[1]. As a result, many scholars began to focus their study on the microstructure of soil attempting to establish a microstructure model of soil to explain mechanic behavior of soils and prompt Soil Mechanics from brand-new perspectives. By now, the development in soil microstructure study is gestating a new branch of Soil Mechanics Microstructure Soil Mechanics[1].

In the same way, study on the microstructure of loess is bound to be the very field where major breakthroughs are expected for loess soil dynamics. Nevertheless, How to analyze and apply Scanning Electronic Microscope (SEM) properly in study is often proven not to be a simple question and there are some problems to be mulled.

1 Principles for Loess Microstructure Image Analysis

First of all, there should be some clear ideas in mind before any study on loess microstructures. Loess microstructure images are never omnipotent evidence in study. On the contrary, limitations caused by technology deficiency and current research level make the study on soil microstructure much likely to be misleading and having a higher proportion of uncertainty. Hence, it is necessary having a better mastery of the study subject and key elements of microstructure analyzing.

Usually, the purpose of loess microstructure study could be: 1) to establish loess microstructure model; 2) to explain or understand the macro soil mechanical property of loess through its microstructure features; 3) to compare the microstructure difference between different types of loess. The different aspects of loess microstructure are considered and the different kind of analysis is needed for different purpose of study. If the purpose is to establish the microstructure model of loess, it is necessary to conceive a universal set of microstructure parameters to express the particle contact and composition of pores of loess, which is the basis for any theoretical microstructure soil mechanics model of loess. If the purpose is to explain or understand the static or dynamic Soil Mechanics properties of loess, the first thing is to determine the right microstructure features related to these properties. For example, for study on seismic subsidence of loess, the tiny and small pores in pores classification should be excluded, because these pores are relatively stable and would not change much under dynamic stress. Therefore they are not very relevant to seismic subsidence of loess and most of the attention should be given to the changes of the trellis structure, which is a particular feature in the microstructure of loess, and middle pores [2]. For the comparison of microstructure between different types of loess, the first thing needs to do is determining whether the main difference is of gradation or of microstructure properties. If it is the microstructure properties, then it should be determined that among particle contact, particle configuration and pores composition, which is the major reason behind. Overall, if there is a clear idea of what to do, there is less chance that study will go astray and research is not to be confused by a variety of microstructure terms.

Secondly, the microstructure of loess has so many aspects that makes quantification or description of it very complicated. It is only practical to select the most related certain aspects to deal with in study. Fig. 1 shows the classification of parameters of microstructure of loess. Under every major aspect there are subdivisions.

Sometimes, preliminary study is necessary in order to choose the right and the most relevant indices of loess microstructure in study. To take the loess liquefaction as an example[3], the particle contact, gradation composition and pores distribution are of the most importance. Apart from these, particle arrangement is also a factor needs to be take into consideration. Generally, study on the microstructure of loess should choose the parts that are the most relevant with soil mechanical problems of concern.

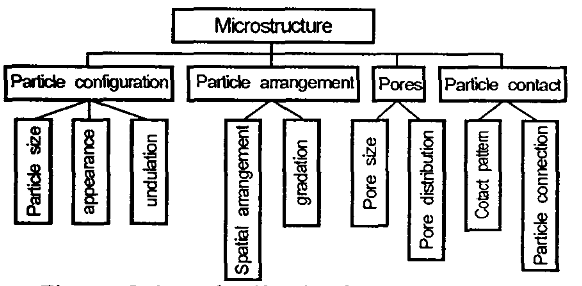

Fig. 1 Indices classification for Loess microstructure morphology[1]

2 The Sale Effect of Loess Microstructure and Corresponding Structure Information

The magnification times of SEM ranges from scores to tens of thousand. With different magnification, the resolution variation of SEM images causes the main revealed microstructure information changes. In other words, there is a scale effect for loess microstructure. For this reason, some scholars tend to use the term "fabric" instead of microstructure, because the structure characteristics of soil left their footprints from the millimeter scale to the nanometer scale. For such a wide range of scale variation, it may not proper to use " microstructure" in a sense. Under different resolution scale the structure features can be observed are different, which reveals the structure of soil from different level.

Fig. 2 show the SEM images of loess at magnification times of 50, 200, 500 and 1 000(M. T: magnification times).

With the magnification times of 50 (Fig. 2 (a)), the main features revealed in the SEM image are the glaebules composed of smaller particles and sand. Apart from these, an elongated object at the upper right corner of the image is plant root. Affected by climate, moisture content and gradation, the configuration of glaebules and their contact are different for different loess. The glaebules are built on skeleton of coarse sand and filled with fine content (mainly silt and clay). Loess, especially those come from Lanzhou, has high content of silt, whose size ranges between 5 to 50 μm[4]. These particles only subject to minor effect of the electronic attraction force and can fill in relatively even in the skeleton, which makes it integrated well within the glaebules and show false "particle" appearance under low magnification times. But the loess glaebules are "water sensitive" and fragile. Under high moisture content or vibration, glaebules and secondary pores (fissures, pore formed by glaebule contact, root holes and corrosion void) among them would crumble. The fabric characteristics of glaebules have certain relationship with the current climate, vegetation, underground water and human activities, which makes the study of it very valuable not only in Soil Mechanics but also in Agrology. According to Zhao jingbo [5], some kinds of loess are not only Aeolian sediment, but also paleosoils have been withstanding soil formation. Thus study of loess microstructure under low magnification times is an effective means to understand the soil formation of loess as paleosoil and recent climate and organism conditions. Generally speaking, magnification times from 50 to 150 can meet the needs of loess glaebules study.

Fig. 2(b) is the SEM image of loess with magnification times of 200. Most of the silt particles can be identified in this image. Obviously, the constituting minerals are mainly rock-forming minerals like quarts, feldspar and mica. These minerals are relatively crystallized well and in form of semi-regular flake or prism with symmetry of certain degree. Also, with this magnification times, the pore structures of loess are partially shown, especially the large and the middle pores which could be analyzed. The particle contacts between coarse particles which composes the skeleton of soil structure can be identified and so do the most of the trellis structures and part of the intertwine pores. Although the details of small pores, particle configuration, contacts and cementation cannot be observed, the SEM image with this magnification provides a relatively holistic view of the loess microstructure and a reliable results could be obtain by analyzing of only a few of images.

Fig. 2(c) is the SEM image of loess with magnification times of 500. In the image the pore structures and the particles larger than the silt could be differentiated well. The pore features mostly interested in Soil Mechanics study can be identified under this circumstance and so do the configuration of silt and fine sand particles. Experiences tell that a complete picture of the pore distribution and pore features can be obtained by choosing a low magnification times and a higher magnification times of observation within the range of 200 to 600. However, it is advisable that more frames of SEM image should be selected for analyzing at high magnification times.

Fig. 2(d) is the SEM image of loess with magnification times of 1000. In the image the cascade feature of clay minerals can be observed. Most exterior characteristics of the clay particles can be observed under this circumstance. Usually, magnification times larger than 1000 is regarded as high end of observation, which is suitable for the revealing of the degree of cementation, nature of cementation and particle configuration etc [5]. The information is useful for the understanding of the formation of loess particles, degree and type of cementation and geologic times [6].

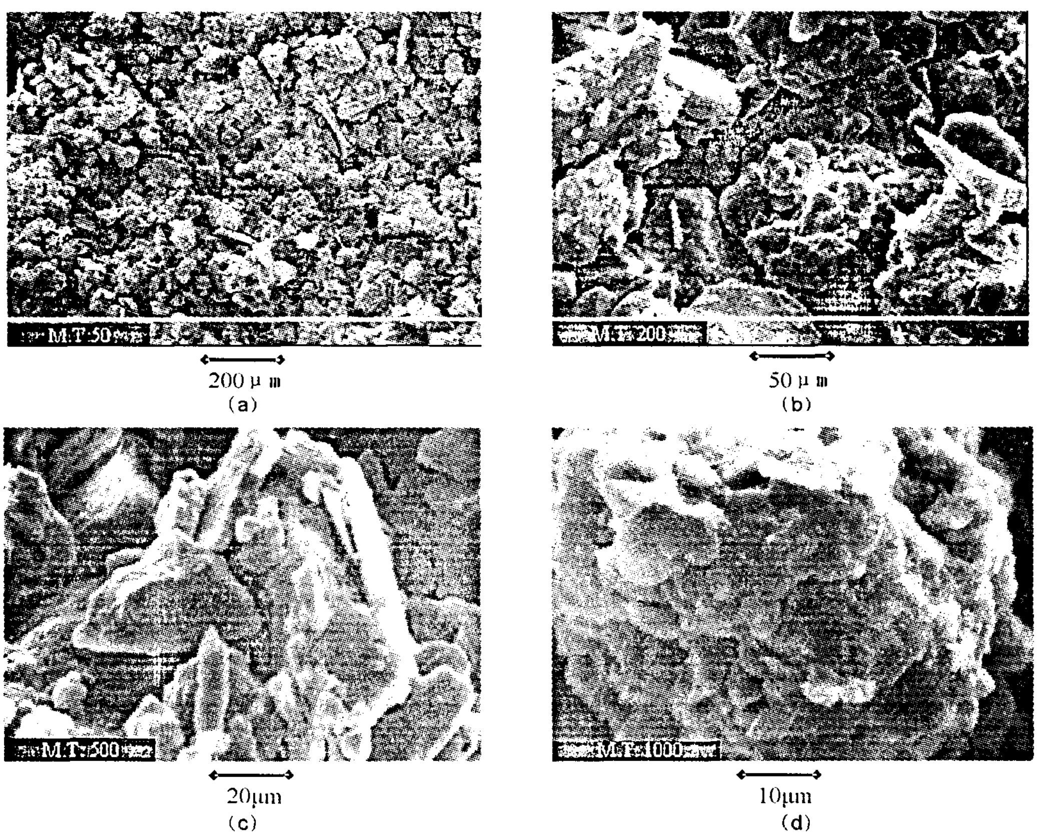

Fig. 2 Loess SEM images in different magnification times.

Based on the above-mentioned apprehension, the main microstructure information revealed by SEM images with different magnification times can be summarized as following (Table 1):

However, it needs to be clarified that the relationship between the magnification times and microstructure given in Table 1 is not exclusive. It is relatively because of the fact that the difference of loess structure could be substantial sometimes. Hence, there should be variation allowance of magnification times to observation certain microstructure features.

Table 1 The microstructure information mainly revealed with different magnification times

Magnification times	50	150	200	400	500	800	1000	1500	>1500
Pore features			—	—	—	—			
Glaebule features	—	—							
Particle contact				—	—	—	—		
Particle configuration & cementation				—	—	—	—	—	—
Particle arrangement			—	—	—	—	—		

—: Corresponding microstructure feature can generally be observed with this magnification times.

3 Initiatives on the Microstructure Classification of Loess

A step further, the authors consider that it is to classify the microstructure of loess to reflect the scale effect of structure of loess under different resolution of observation. On one hand, the structure features that can be observed are different with substantially different magnification times. On the other hand, the microstructure classification based on scale of observation would provide means to describe different aspects of microstructure of loess to avoid confusion in study with adoption of proper terms. The authors propose that the structure features related to the glaebules and their contact should be classified as *Intermediate Microstructure* (Magnification times less than 200 usually). The structure features reveal the configuration of sand and silt particles, particle contact and most of pores meaningful for Soil Mechanics studies can be classified as *Microstructure*. Finally, the structure features observed with magnification over 1000 that reflect the particle configuration of clay and details of cementation can be classified as *Sub-microstructure*. Different microstructure class reflects different aspects of soil microstructure of loess and they also have different meaning in Soil Mechanics study. The Intermediate Microstructure of loess is much more related to the current climate, organism condition, human activity etc, which is highly valuable in agrology study. The Microstructure of loess reflects the sedimentation condition, mother rock, soil stress history and other Soil Mechanics (Soil Dynamics included) characteristics and most of the microstructure study relevant to Soil Mechanics is concentrated in this domain. The Sub-microstructure of loess reveals the features of clay minerals and cementation. Apart from application in Soil Mechanics study in particular cases, it is also useful in the study of Quaternary Geology.

4 Discussion on the Pore Classification of Loess

The pore classification now used is based on the classification proposed by GUAN Wen-zhang [7]. The criteria of classification are shown in Table 2.

Table 2 The loess pore classification proposed by GUAN Wen-zhang [7]

Pore class	Diameter /μm	Origin
Large pore	>32	Secondary pores (root/worm holes, corrosion void, inter-glaebule pores)
Middle pore	8~32	Inter-particle pores, trellis pores and crystal pores
Small pore	2~8	Intertwine pores, inter-silt particle pores
Tiny pore	<2	Inter- clay particle pores

In our study, it is found that this classification is flawed. One is that the classification of pores with diameter between 1~5 μm is unnecessary. To make these pore identifiable, the magnification times should be over 800, usually be 1 000. The pores of this size are of three categories: 1) inter-particle of clay; 2) the voids in the intertwine - pores and 3) the corrosion void or fissure on mineral crystals which reflect mineral generating and changes in geologic times. Pore diameters small than 5 μm will not be changed under mechanical effect [8], they are bounded by electric force between fine contents(clay and silt) and the cementation of intertwine pores. And from the point view of Soil Mechanics, these pores are stable and should not be taken into consideration. The second is that the pores classification had no concerns on grain gradation classification. For the pore with diameter larger than 5 μm, the size of pore determined the fillings and composition. Hence, it is necessary to take the grain gradation classification as a reference. Third, the trellis pores may have size far lager than 16 μm. As reported by ZHANG Z Z, et al [9], the largest diameter of trellis pore observed in SEM image of loess is as large as 202 μm.

The authors argue that the classification of loess pores should follow these principles: 1) To consider the nature of pore origin; 2) To take grain gradation classification as a reference; and 3) To classify those pore of similar Soil Mechanical - mechanism as one group to make it convenient in study.

Using the discussion on loess pores in reference [8], the following classification of loess pores is proposed.

Table 3 The loess pore classification proposed by the authors

Pore class	Diameter /μm	Origin
hole	>250	Secondary pores such as: hole formed by organism, joints in loess and other pore could be eye-differentiated
Structure pores	50～250	Trellis pores, inter glaebule pores. They crumble easily and loess seismic subsidence is largely related to these pores.
Inter-particle pores	5～50	Inter-particle pores and intertwined pores. They are partially changeable.
Micro-pore	<5	Inter-clay particles pores, pore between silt-clay particles, fissures and corrosion void in mineral crystal. Usually stable under mechanical effect.

Using this classification proved to be more practical in our study. For example, in the study of seismic subsidence of loess with pore, the authors find that the number of structure pores in same size in the loess sample after seismic subsidence test is 1/4 less than that in original samples, while the maximum diameter of structure pores reduces to 1/2 of that in original samples. The total area of structure pores in the loess sample after seismic subsidence test is only about 50% of that of the original sample. Using this classification, the micro-pore are not taken account, thus the amount of work is reduced sharply. In most cased of Soil Mechanics study, it is enough to take only account of the changes of the structure pores and the inter-particle pores.

5 The selection of SEM images for study

In the loess structure study using SEM images, the analysis on image should obey the rules of "partial analysis to be combined with over analysis while more attention is paid to the key resolution scale". Namely, several magnification times from around 100 to 1 000 should be selected to get an overall understand of fabric of loess. Taking the problems to be studies in mind, extensive care should be given for SEM image of loess under certain magnification times of observation.

The selection of magnification times should be determined by the problems of study. As it is mentioned above, the intermediate microstructure reflects the structure characteristics of glaebules and coarse grains. Microstructure is most related to inter-particle contact, cementation and configuration of particles larger than silt. The sub-microstructure can reveal the appearance of mineral, cementation detail, clay particle and blocks of clay particles. At the same time, other information about the gradation, condition on origin and other particularities (salt, high silt content etc.) are also reference for the selection of SEM image in study.

Finally, SEM image analysis also needs to "pay much attention to specialty and to be combined with other types of test data". The specialties are often clues leading to the resolving of cruxes. It is usually impossible to get a clear understanding with SEM image analysis alone, other Soil Mechanics test should also be given enough attention in a study.

6 Conclusions

1) In the applying of SEM images in the Soil Mechanics study, it is important to have some knowledge on the relevance between the problems in study and the set of structure indices and thus to

choose those important aspects of fabric of loess only.

2) With different magnification times of observation, the microstructure characteristics could be revealed is different. This causes an " scale effect" for SEM image study. In a study, the problems of study should be related the certain observation resolution for detailed study.

3) The authors consider that the term "microstructure" is too general for the facts that observation ranges from magnification times from tens to over one thousand. For the purpose of precise description, the definitions of intermediate microstructure, microstructure and sub—microstructure are proposes to differentiate microstructure features under substantial different magnification times of observation.

4) Finally, based on study results, a new classification of loess pores is proposed for the inconvenience and flaws in existing classification. Combined with gradation classification and the nature of pores, the new classification thought to be more appropriate in study.

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