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Quartz sand surface morphology of granitic tafoni at Laoshan, China

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In this study, a SEM method was used to analyze the surface morphology of the quartz sand granitic tafoni at Laoshan, for the purpose of exploring the weathering process of this tafoni. Present study showed that granitic tafoni at Laoshan, the quartz sand roundness was dominated by angular and sub-angular morphologies. Massive Hydrodynamic features had been developed on the quartz sand surfaces, as well as wind and chemistry forms, which were more developed. It was determined that granitic tafoni at Laoshan, the quartz sand had suffered long-term rainy and windy mechanical erosion, as well as chemical dissolution from residual pit water. These findings differed from the earlier views that the tafone was formed by the glacial melt water.

[Keywords: granitic tafoni, quartz sand, surface features, SEM, Laoshan.]

Introduction

Rock surface weathering is a major factor which is associated with the creation of diversified geomorphologies[1,2]. Weathering can be formed in various rock areas, the most typical being granite. Some of the original small pits on granite surfaces, which had undergone weathering and constant expansion, formed into granitic tafoni landscapes. Previous research studies have shown that granitic tafoni weathering is caused by water ponding. After the tafoni becomes saturated with water, the water overflows from the lower rock slopes to form outlets, which leads to the leaching of the soluble elements in the rock. Following the rock decomposition, the residual clastic particles tend to remain within the granitic tafoni[3,4]. Among these, the residual quartz sand in the tafoni has a strong weathering resistance, and retains the obvious microscopic features of the surface. At the present time, the debates regarding the genesis of this tafoni are fierce, and include various theories, such as the pothole, glacial potholes, weathering pit, and bubble-like caves (geode) theories. In this study, scanning electron microscope observation was used to examine the surface morphological features of the quartz sand granitic tafoni at Laoshan, in order to further explore the weathering process of this tafoni.

Materials and Methods

Laoshan is located along the banks of the Yellow Sea (Fig. 1), which is the highest peak in China's coastal zone. The Laoshan rock mass consists of alkaline granite from the late Yanshan movement[5,6]. The Laoshan granite has a strong weathering effect, and various differently sized tafoni have developed on the rock surfaces.

In this study, samples were taken from the clastic sediments in granitic tafoni located in Lingqi Peak, Yangkou Scenic Area, and Qipan Scenic Area at

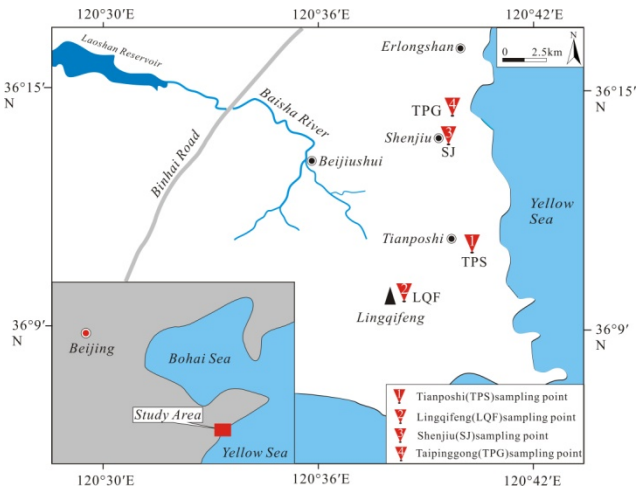

Fig. 1 — Study area

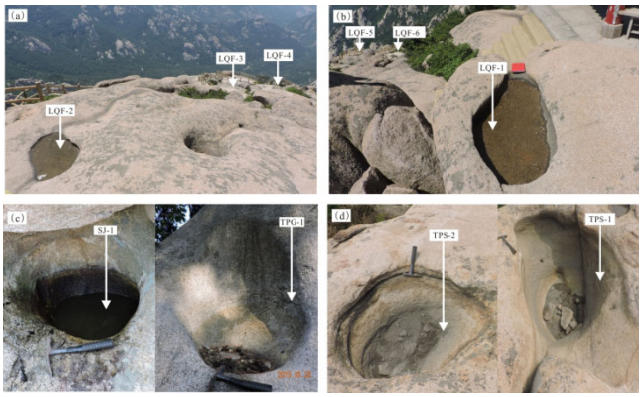

Fig. 2 — Location of sampling

Laoshan Mountain Top (Fig. 2). The selection and processing of the quartz sand are shown below[7,8]. Then, 50 g of the clastic material (60 to 80 mesh) was weighed, and it is added to 15% diluted hydrochloric acid for a 24-hour soaking process. The $CaCO_3$ on the particle surface was removed by repeated washing with distilled water, and the samples were boiled for five minutes in oxalic acid to remove the ferric oxide film on surface of the quartz. Then, distilled water was used for thorough rinsing, and the samples were dried. Using a stereoscope, 10 to 15 grains of quartz sand were arbitrarily selected, with representatives to avoid the same morphology. A certain gap was maintained between the quartz lines and grains for the installation of electron microscope sample piers with double-sided adhesive. They were then placed in a standard vacuum coating machine to apply a layer of conductive gold film for the testing process. The SEM analysis was completed in the SEM Lab at the Shandong University of Science and Technology. The instrument used was an Nova-type high-resolution SEM, and 300 photos were taken regarding the surface features of the quartz sand examined in this study.

Results and Discussion

The roundness and surface morphology of the quartz sand reflected the sediment transport distance and process. In regard to the tafoni at Laoshan, the quartz sand was found to have diversified surface morphologies, mechanical and chemistry features.

The mechanical features refer to the quartz sand in the tafoni having undergone all types of mechanical forces during the transport process. These forces have left traces, which mainly included the quartz sand roundness, and hydrodynamic and wind effect features.

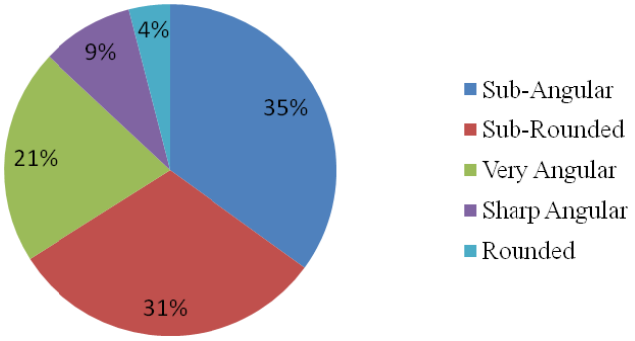

Fig. 3 — Frequency of roundness

According to previous studies, it has been determined that the roundness of quartz sand has certain instructional significance to the sedimentary environment and transport process. For example, angular quartz sand with poor roundness generally has had a short transport distance or weaker hydrodynamics of provenance. Therefore, based on the principles of Powell's roundness hierarchies[9,10,11], the quartz sand grains in Laoshan's tafoni were divided into five roundness levels: sharp angular, very angular, sub-angular, sub-rounded, and rounded. The SEM analysis results showed that the angular, very angular, sub-angular, sub-rounded, and rounded quartz sand accounted for 9%, 21%, 35%, 31%, and 4% (Fig.3).

The wind features mainly includes dish-shaped pits, crescent-shaped steps, pockmarked pits or surfaces, and upturned cleavage flakes (Fig. 4). It is generally believed that dish-shaped pits (Fig. 4A and B) and crescent-shaped steps (Fig. 4C and D) are mainly formed under the conditions of strong storms which have resulted in mechanical impact effects, and high-energy aeolian environments are a particular indication of aeolian quartz sand[12,13,14,15]. Pockmarked pits are the fine pits on quartz sand surfaces which resemble scars (Fig. 4E and F). These are not only the traces of quartz sand undergoing erosion during the wind transport processes, but also the peculiar surface structure of quartz sand. The upturned cleavage flakes (Fig. 4G) are formed by the inter-granular erosion of quartz sand during the transport process. They are generally considered to be the most often developed in aeolian environments, but are not restricted to only aeolian environments. Among the Laoshan quartz sand samples in this study, the occurrence frequencies of dish-shaped pits, crescent-shaped steps, pockmarked pits or surfaces, and upturned cleavage flakes were determined to be 5.3%, 6.8%, 9.1%, and 1.5%, respectively in the Laoshan tafoni. For

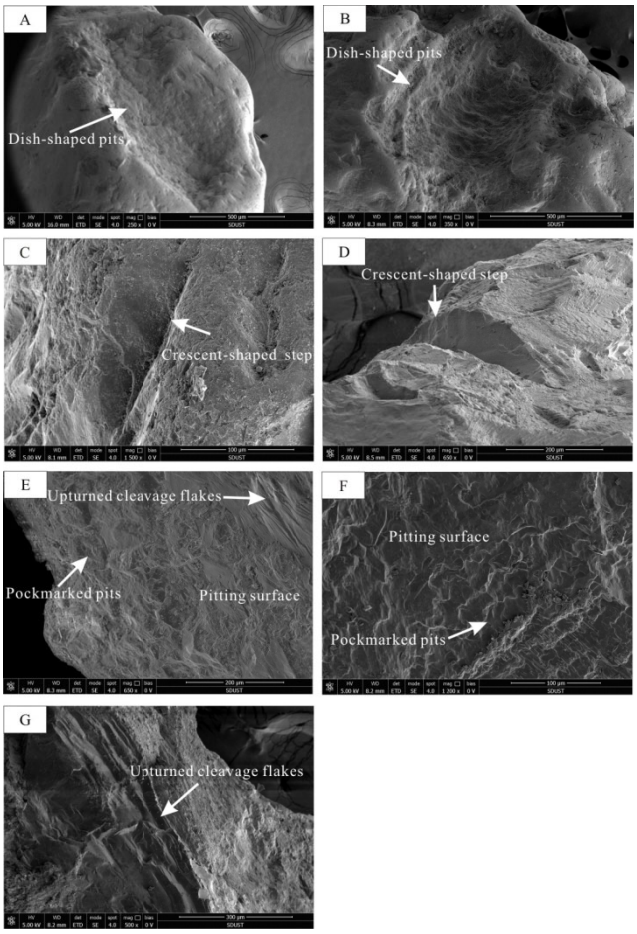

Fig. 4 — Quartz grains microtextures of the wind features

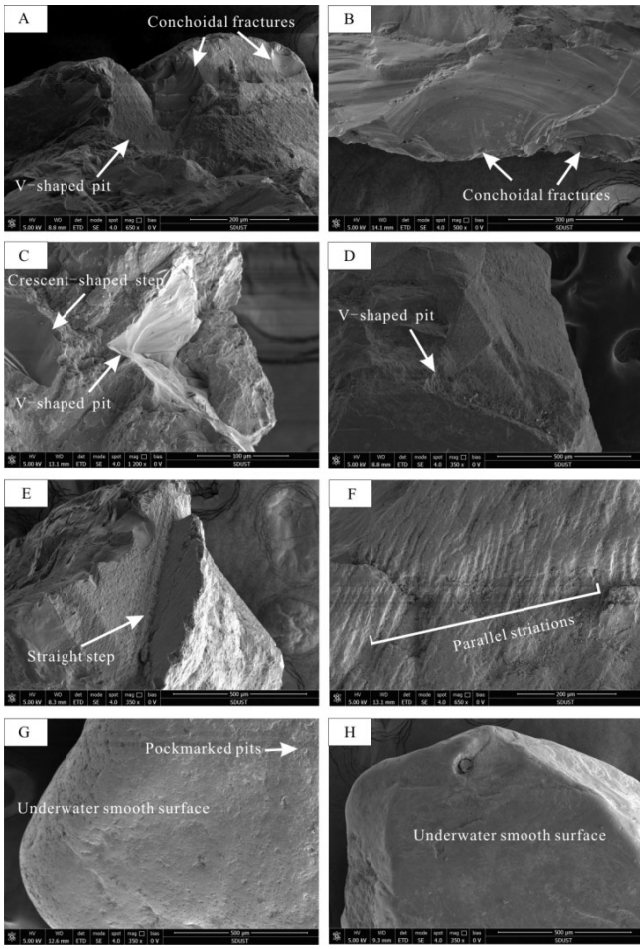

Fig. 5 — Quartz grains microtextures of the hydrodynamic features

example, in this study, the majority of the quartz sand in the Laoshan tafoni was determined to be very angular, sub-angular, and sub-rounded with poor roundness.

Hydrodynamic features were found to be very developed on the quartz sand surfaces of tafoni at Laoshan. These included conchoidal fractures, V-shaped pits, underwater smooth surfaces, parallel striations, and straight steps (Fig .5). However, some of the Hydrodynamic features had been eroded or transformed, and had become blurred. It is generally believed that conchoidal fractures not only appear during wind transport, but also massively occur in underwater environments[16,17,18,19]. Among the samples of the tafoni at Laoshan, conchoidal fractures were very developed and were found in almost every sample (Fig. 5A and B), with an occurrence frequency as high as 31.1% (Table 1). V-shaped pits (Fig. 5C and D) and straight steps (Fig. 5E) are also typical features of hydrodynamic features. Among the samples of the tafoni at Laoshan, V-shaped pits were well developed, with an occurrence frequency of 25%. Under the conditions of a relatively stable hydrodynamic action, parallel striations (Fig. 5F) will undergo subsequent mechanical collisions. Also, under the effects of hydrodynamic mechanical abrasion, quartz sand surfaces will become smooth and form clear underwater smooth surfaces (Fig. 5G and H). In addition, Hydrodynamic features and wind action features may appear simultaneously, or overlap on quartz sand surfaces. For example, conchoidal fracture may be overlapped by a crescent-shaped step (Fig. 5A), and the parallel arc curve on the fracture becomes damaged.

The Chemical features refer to the features of quartz sand undergoing chemical actions in sedimentary areas, and are mainly divided into three aspects: SiO_2 dissolution, SiO_2 deposition, and crystal growth[20,21,22]. These features include flaking away, solution pits and grooves, smooth silica veneers, siliceous film, crystal growth, and so on. By using SEM to study the Laoshan quartz sand samples, the

chemical dissolution and precipitation phenomena were also determined, which indicated that the quartz sand in the tafoni at Laoshan was not only affected by wind and hydrodynamic actions, but also underwent chemistry processes. The previous research has shown that different quartz sand surface parts indicate various degrees of resistance to chemical corrosion[23,24]. Flaking away refers to the dissolution which begins on the surface of quartz sand, including flaws or weak resistance to chemical corrosion, then gradually expands to eventually form different scales of flaking cleavage (Fig. 6A and B). As a chemical dissolution deepens into the grain interior, irregular forms of solution pits and grooves mainly occur (Fig. 6C). However, the dissolution is often accompanied by obvious precipitation. The dissolution SiO_2 is deposited on the surface of the quartz particles the grain surface, and then slowly accumulate to form flaking or petal smooth silica veneers (Fig. 6D-F), of which the smooth silica veneers are further developed to expand the coverage and form into siliceous film.

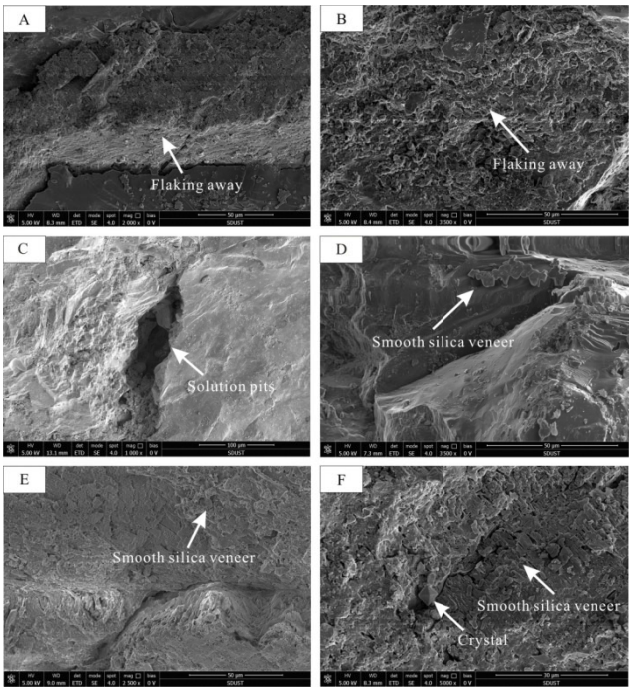

Fig. 6 — Quartz grains microtextures of the chemical features

Relationship between the quartz sand surface features and the sedimentary environment. As previously mentioned, it was determined in this study that the grains of the Laoshan quartz sand were dominated by angular, sub-angular, and sub-rounded morphologies, which indicated a near-distance transport. The quartz sand surfaces had the aeolian features of dish-shaped pits, crescent-shaped steps, pockmarked pits, and upturned cleavage flakes, which represented an aeolian environment. Meanwhile, the grain surfaces also displayed the underwater environment features of conchoidal fractures, V-shaped pits, straight steps, parallel striations, and underwater smooth surfaces. In addition, the grain surface also presented the chemical dissolution and precipitation features of flaking away, smooth silica veneers, and deep irregular solution pits with the occurrence frequencies of 22.8%, 68.9%, and 8.3% (Table 1), respectively. According to the surface features of the quartz sand grains in the different sedimentary environments[25,26,27] (Table 2), the surface features of the quartz sand in the tafoni at Laoshan were very similar to those of a water-ponding sedimentary environment. These findings indicated that the quartz

Table 1 — The surface features statistics of the quartz sand

Surface micro textural features		Sample points								
		LQF-1	LQF-2	LQF-3	LQF-4	LQF-5	LQF-6	TPS-1	TPS-2	SJ
Wind features	dish-shaped pits	2	1	_	_	2	_	_	2	_
	crescent-shaped steps	3	_	1	_	_	1	3	1	_
	pockmarked pits or surfaces	1	_	1	2	_	1	3	1	3
	upturned cleavage flakes	_	_	_	_	_	_	_	_	_
Hydrodynamic features	conchoidal fractures	4	5	_	5	7	6	6	2	6
	V-shaped pits	_	3	4	8	2	5	3	_	3
	straight steps	_	1	_	3	2	_	1	_	_
	underwater smooth surfaces	_	2	_	_	3	_	_	_	_
	parallel striations	2	_	_	_	_	_	2	_	_
	flaking away, siliceous film	_	_	_	_	_	2	_	_	_
Chemical features	solution pits and grooves	1	_	_	2	_	_	_	_	_
	smooth silica veneers	_	_	_	1	1	_	_	_	3
	crystal growth	_	_	_	1	_	_	_	_	_

Table 2 — Surface features of the quartz sand particles in different sedimentary environments12

Sedimentary environment	Surface features of quartz sand
Aeolian environment	(1) better roundness; (2) upturned cleavage flakes exist; (3) crescent-shaped steps and dish-shaped pits exist.
Residual slope water environment	(1) conchoidal fractures; (2) sharp points; (3) upturned flakes exist; (4)chemical dissolution and precipitation; (5) underwater smooth surfaces.
Glacial environment	(1) angular; (2) conchoidal fracture is developed; (3) parallel striation and scrape exist; (4) extrusional pits and impact pits often exist.
Glaciofluvial environment	(1) glacial environment features exist; (2) underwater polishing surfaces exists; (3) V-shaped pits; (4) dissolution effect is strong with the conchoidal fracture.
Alluvial environment	(1) better roundness; (2) underwater smooth surfaces; (3) V-shaped pits; (4) impact pits and conchoidal fracture.

sand in the tafoni at Laoshan had been mainly affected by the scouring of tafoni water, as well as the rainfall from the tafoni at mountain top. During the dry seasons, this exposed tafoni water on the top of Laoshan was dry, and the clastic particles in the tafoni experienced wind actions for re-transport and transformation.

Therefore, aeolian features were clearly maintained on the quartz sand particles. Moreover, the superimposition of some of the different genetic features reflected the effects of multiple wind and hydrodynamic actions on the quartz sand. Furthermore, affected by the tafoni water and marine climate, the chemical dissolution and deposition were relatively developed on the quartz sand surfaces. This study's research results are therefore different from the previous opinion that the tafoni in this location was formed by the high-speed flow erosion of melting glacial water.

Conclusions

In this study, by using a SEM method, the surface features of the quartz sand particles in the tafoni at Laoshan were studied. The following conclusions were obtained:

The quartz sand of the tafoni at Laoshan was mainly sub-angular to sub-rounded forms. Also, crescent-shaped steps, pockmarked pits, dish-shaped pits, and other wind features existed on the surfaces. It was found that conchoidal fractures, V-shaped pits, underwater smooth surfaces, and other Hydrodynamic features were developed. Meanwhile, the features of certain chemical dissolution and precipitation effects were found to exist. The statistics showed that the occurrence frequencies of the hydrodynamic, wind, and Chemical features were 68.5%, 22.6%, and 8.9%, respectively. Studies have shown that the quartz sand particles in the tafoni at Laoshan have not only experienced the mechanical effects of water and wind actions, but also have been affected by the chemical dissolution and precipitation of tafoni water. The research results of this study are different from the previous conclusion that the tafoni at Laoshan was formed by glacial melt water.

Acknowledgement

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References

1 Wang W., Zhou S. Z., Li B. Y., Xie B., Feng X. Z., Queries about the glacial potholes of mountain Laoshan, China. *Quaternary Sciences*, 31(5), (2011), 917-932.
2 Goudie A. S., Encyclopedia of Geomorphology. *Routledg*, (2004), 1115-1116.
3 Twidale C. R., Romani J. R. V., Landforms and geology of granite terrains. *Taylor & Francis*, (2005), 207-234.
4 Migon P., Granite Landscapes of the World. *Oxford University Press*, (2006), 132-160.
5 Song Z.J., Liu X.Q., Tang W.J., Gao L., Li J.P., Luan S.G., of Large Bubble-Like Caves in the Laoshan Granites and its Significance. *Acta Geologica Sinica*, 90(1), (2016), 394-395.
6 Song Z.J., Tang W.J., Gao L., Liu X.Q., Chang X.C., Li J.P., Chemical Index of Alteration to describe the Chemical Weathering of Laoshan Natural Mortar. *Chimica Oggi-chemistry Today*, 34(6B), (2016), 27-32.
7 Han J. E., Yu J., Meng Q. W., Lv R. P., Zhu D. G., Meng X. G., Shao Z. G., Yang C. B., Quartz grain surface characteristics of sediments from the Zanda Basin of Tibet and their environmental significance. *Acta Geoscientica Sinica*, 30(5), (2009), 651-658.
8 Li M. H., Kang S. C., Zheng M. P., Surface textures on quartz grains from the Zhabuye Saline Lake in the Middle Tibet Plateau since 142 ka BP. *Journal of Glaciology and Geocryology*, 30 (1), (2008), 125-131.
9 Xie Y. Y., Micrograph atias of surface texture features of quartz sand in china. *Ocean press*, (1985).
10 Wang Y., Deonarine B., Model atlas of surface textures of quartz sand. *Science Press*, (1985).
11 Wu Y. Q., Cui Z. J., Ge D. K., Liu G. N., Surface character and sedimentary environment of the quartz grains in the

Quaternary Strata in Kunlun Mountains Pass Area. *Journal of Basic Science and Engineering*, 6(2), (1998), 117-124.

12 Chen L. H., Miu X., The application of scanning electron microscopy (SEM) in geology. *Science Press*, (1986), 171.

13 Moral C. J. P., Gutierrez M. J. M., Sanchez B. A., Dominguez-bella S., Martinez L. J., Surface textures of heavy-mineral grains:a new contribution to provenance studies. *Sedimentary Geology*, 174, (2005), 223-235.

14 Wang W. Y., Some properties of surface microtextures of quartz sand from tuomuerfeng, Tianshan mountain. *Bulletin of the Institte of Mineral Deposits Chinese Academy of Geological Sciences*, (1982), 75-79.

15 Sun Y. B., An Z. S., Sedimentary interpretation of surface textures of quartz grains from the eolian deposits. *Acta Sedimentologica Sinica*, 18(4), (2000), 506-509.

16 Gobala K. N., Nagendra R., Elango L., Quartz surface microtextural studies of Cauvery River sediments,Tamil Nadu, India. *Arabian Journal of Geosciences*, (2015).

17 Yu L. F., Yang Z. J., Zhou Y. Z., Zhao W. X., Li H. Z., Gu Z. H., The application summary of scanning electron microscope (SEM) and environment scanning electron microscope (ESEM) in geosciences. *Journal of the Graduates Sun Yat-Sen University(Natural Sciences, Medicine)*, 29(1), (2008), 54-61.

18 Shi L., Zhang Y., Chen Y. X., Fu H. R., Liu G. N., Quartz grain SEM microtextures analyses of Sub-Glacial Deposits at Hailuogou Glacier. *Acta Scientiarum Naturalium Universitatis Pekinensis*, 46(1), (2010), 96-102.

19 Fan Q. B., Ye W., Chen Q., Surface morphology of quartz grains from the Henggang “sand dune” at Nanchang County, Jiangxi Province. *Arid Land Geography*, 37(5), (2014), 1170-1181.

20 Zhang J. W., Wang X. K., Yuan X. L., Guo H. L., Shen W. X., Chen Y., Zhou C. Z., Quartz sand surface characteristics of quaternary sediments and sedimentary environment indicator in south slope of Mount Tai. *Global Geology*, 30(3), (2011), 463-468

21 Krinsley D., Takahashi T., Applications of electron microscopy to geology. *New York Academy of Science. Trans*, 25(3), (1962), 3-22.

22 Newsome D., Ladd P., The use of quartz grain microtextures in the study of the origin of sand terrains in Western Australia. *Catena*, 35(1), (1999), 1-17.

23 Mahaney W. C., Dirszowsky R. W., Milner M. W., Menzies J., Stewart A., Kalm V., Bezada M., Quartz microtextures and microstructures owing to deform ation of glaciolacustrine sediments in the northern Venezuelan Andes. *Journal of Quaternary Science*, 19(1), (2004), 23-33.

24 Strand K., Immonen N., Dynamics of the Barents-Kara ice sheet as revealed by quartz sand grain microtextures of the late Pleistocene Arctic Ocean sediments. *Quaternary Science Reviews*, 29, (2010), 3583-3589.

25 Udayaganesan P., Angusamy N., Gujar A. R., Rajamanickam G. V., Surface Microtextures of quartz grains from the central coast of Tamil Nadu. *Journal Geological Society of India*, 77, (2011), 26-34.

26 Song H. C., Meng Q. Q., Xia W. M., Xu L., Miao Y. F., Yang Y. B., Hu S. H., The eogene surface texture of quartz sand and paleoclimatic change in Northern Margin of Tibetan plateau. *Acta Sedimentologica Sinica* , 27(1), (2009), 94-103.

27 Armstrong-altrin J. S., Natalhy-pineda O.: Microtextures of detrital sand grains from the Tecolutla, Nautla, and Veracruz beaches, Western Gulf of Mexico. Mexico: implications for depositional environment and paleoclimate. *Arabian Journal Geosciences*, 7, (2014), 4321-4333.