Magnetic fabric study of the Keziletage pluton in east part of southern TianShan and its tectonic implications

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Abstract: The Keziletage pluton which plays an important role in studying the nature of continental lithosphere and restraining the tectonic evolution of the Southern TianShan orogenic belts is located in the middle of the Keziletage synclinorium, a secondary tectonic unit of the South TianShan syncline fold belt. Emplacement mechanism of the Keziletage pluton in Xinjiang is studied through detailed analyses of magnetic fabrics. Data from 28 sampling sites within the pluton show that the value of the average susceptibility ($K_m$) is high. The corrected anisotropy degree ($P_j$) is less than 1.2, which can be an indicator of flow magnetic fabrics. The shape parameter ($T$) of magnetic susceptibility ellipsoid displays that the Keziletage pluton is dominated by oblate compression fabric. Although the magnetic fabrics show NE-SW compression as a whole, the magnetic lineations are little over magnetic foliations. We suggest that the collision of Tarim blocks to YiLi-mid TianShan micro-plate became much weaker during the emplacement when the regional tectonic setting was changing to extension environment.

1. Introduction
The relative difficulty of material magnetization in different directions can be represented by anisotropy of magnetic susceptibility (AMS). Anisotropy of magnetic susceptibility is always used to study fabric characteristics and structural deformation of rock, which was called analysis of rock magnetic fabric, first proposed by Graham [1]. The magnetic minerals in granitic magma shows a certain optimum arrangement orientation when forces act on them during magma emplacement and condensation. After complete condensation and consolidation, the magnetic fabric of rock mass is relatively stable and it is difficult to change under the condition of brittle deformation at low temperature and pressure[2,3]. Therefore, the granite retains various records of generation, transport, mixing and deformation of magma [4]. Compared with traditional field and laboratory measurements, it has become an important research method that uses Magnetic Fabric study on magmatic tectonic emplacement dynamics of granite.

The South TianShan orogenic belt lies between the Yili-Kazakhstan plate and the Tarim blocks(Figure 1a), and the main body of the belt has formed a large number of scattered granite rock mass in the process of complex tectonic evolution and crustal accretion. These granitoids play an important role in studying the nature of continental lithosphere and restraining the tectonic evolution of orogenic belts. At present, most scholars believe that the collision occurred in the late Carboniferous period and it has the characteristics of scissors closure from east to west[5-7]. However, some scholars believe that the collision occurred during the Permian period [8].Current studies on emplacement mechanism of granite belt in South TianShan are mainly confined to geochemical data...
and lack of evidence related to tectonic geology. In this study, the magnetic fabric method was used to study the internal fabric of Keziletage rock mass in the eastern part of South TianShan by the author and combined with regional tectonic analysis, and the emplacement mechanism and background of the Late Paleozoic rocks in the eastern part of South TianShan are discussed.

2. Regional geological background

The Keziletage pluton is located in the middle of the Keziletage synclinorium, a secondary tectonic unit of the South TianShan syncline fold belt. (Figure 1b). Keziletage synclinorium mainly consists of Late Paleozoic strata and is dominated by Devonian strata. All of rock strata are subjected to metamorphism and tectonic deformation in different degrees. Most folds with a gentle inclination of both wings are symmetrical linear folds, but in the vicinity of the fault, the dip angle becomes steeper and the inverted fold is formed locally. High-angle reverse faults generally developed in synclinorium. Due to magmatic activity along the fault zone, the arrangement position and extension direction of rock mass coincide with the direction of tectonic line.

![Figure 1](image1.png)

Figure 1. Sketch tectonic location map of the Keziletage pluton (a) and geology map of study area (b).

Keziletage pluton developed in strips along NWW direction and its SHRIMP U-Pb zircon age is 289.9± 8.4 Ma, indicating that the suite formed in the Early Permian (Data to be published). The southern part of the intrusion is located in the Upper Alatage Formation and Carboniferous strata of the Middle Devonian with irregular contact boundary. Obvious baking phenomena, widespread hornfels, local silicification and marble were found in their contact segment. Field geological work shows that the Keziletage pluton is mainly composed of fleshy red K-feldspar granite. Due to the influence of late magmatic differentiation, the content of dark minerals such as biotite and light-colored minerals such as feldspar in rocks is different, which makes the color of rocks change from gray to red, flesh red and light flesh red. A large number of NE-trending faults developed in the rock mass and the fault zone is straight, steep and extends far. The dike rocks in this area mainly occur along NE fault. The main lithologies of the dike rocks are lamprophyre, diorite, diorite-porphyrine and gabbro. The strike of dikes is strictly controlled by NE-trending faults in the rock mass, which occurs in a wall-like manner and steeply dips with lengths ranging from several hundred meters to several kilometers. From the occurrence of intrusion, distribution direction of the dikes rock and slightly equidistant characteristics between veins, it can be considered that they intruded along the same period of tectonic fissures in the early stage.

3. Rock mass characteristics and sampling

3.1 Rock mass characteristics

Typical rock samples were selected for thin section identification, which are mainly fine-grained and medium- and coarse-grained K-feldspar granites. Fine-grained K-feldspar granite is mainly composed of K-feldspar, plagioclase and quartz, with a small amount of biotite. The plagioclase and K-feldspar
are xenomorphic and equiaxed plate shape with mild kaolinitization. The quartz is xenomorphic granular, which distributes evenly between feldspars, while it is fragmented and recrystallized. The biotite has a fine leaf shape and distributes more evenly in feldspars or between feldspars and quartz. Medium and coarse-grained K-feldspar granite is mainly composed of K-feldspar and relatively less quartz, and contains a small amount of plagioclase and biotite, with rare apatite, epidote, magnetite and zircon. K-feldspar and plagioclase are xenomorphic and equiaxed plate shape. K-feldspar is generally coarse perthite. The quartz is xenomorphic granular, which distributes unevenly between in K-feldspars. And the quartz has been fragmented and granulated with strong wavy extinction, which has the characteristics of parallel distribution. Magnetite has xenomorphic grain structure.

3.2 Sampling and Methods
In order to obtain the large-scale stress distribution characteristics of Keziletage pluton, the sampling positions are arranged as evenly as possible. Fresh granite blocks are obtained by grooving machine and orientated in field. Samples were cut into 1.8cm×1.8cm×1.8cm cubic bulk samples in the laboratory. Finally, a total of 172 granite columnar samples were obtained from 28 sites in this study. Measurement of directional magnetic susceptibility of rock finished with Kappabridge KLY-3 magnetization meter in Key Laboratory for Magnetism and Magnetic Materials of the Ministry of Education of Lanzhou University. And major susceptibility ($K_1$, $K_2$, $K_3$) of magnetic susceptibility tensor are obtained by least square method with data processing software Anisoft 4.2 [9].

4 Magnetic fabric analysis
4.1 Average susceptibility
The average susceptibility ($K_m$) reflects the comprehensive characteristics of mineral susceptibility in samples, which is related to the type and distribution of minerals. The low $K_m$ (<500μSI) values usually indicate that magnetism is mainly composed of paramagnetic minerals such as amphibole, biotite, muscovite and chlorite [10], and the high value of $K_m$ is usually composed of hematite, magnetite and other ferromagnetic minerals [11]. Magnetic fabric data of Keziletage pluton are shown in Table 1. The average susceptibility of granite ranges from 107μSI to 8000μSI and the frequency histogram shows that the peak value of the average susceptibility is between 0μSI and 500μSI(Figure 2a). However, the $K_m$ of sample varies greatly and 71% of the data is higher than 1000μSI. According to mineral analysis of the rocks, the main magnetic minerals of the Keziletage pluton are hematite, magnetite and other ferromagnetic minerals.

Figure 2. Histogram of susceptibility( a) , Corrected anisotropy degree(b) and shape parameter (c).
4.2 Magnetic susceptibility ellipsoid and anisotropy

$P_j$ and $T$ are scalar parameters of magnetic susceptibility which indicate the anisotropy and shape of the magnetic susceptibility ellipsoid can reflect the strain characteristics same as the strain ellipsoid [10,11]. The corrected anisotropy degree ($P_j$) of Keziletae pluton ranges from 1.033 to 1.445 with an average value of 1.15, and the frequency histogram shows that the peak value of $P_j$ is between 1.05 and 1.15 (Figure 2b). The magnetic susceptibility ellipsoid shape parameter ($T$) of pluton ranges from -0.593 to 0.537 with an average value of 0.06, and the frequency histogram shows that the peak value of $T$ is between 0.10 and 0.40 (Figure 2c), which shows that compressive deformation is dominant in rock mass. The Flinn diagrams of logarithm of magnetic lineation and foliation (Figure 3a) show that 61% of the samples are located below the line of $\ln F = \ln L$ in the region of flattened ellipsoid with oblateness $E>1$, which has a slight advantage over the points located in the region of stretched ellipsoid. In addition, six points almost fall on the line of $E=1$, which reflect that the sample is nearly pure shear deformation. However, the main deformation of the Keziletae pluton is compression deformation in general.

4.3 Principal axis direction of magnetic susceptibility ellipsoid

The principal axis orientation of the magnetic susceptibility ellipsoid is basically the same as that of the strain ellipsoid, which reflects the dominant occurrence of rock fabric. Minimum axis stereographic projection (AMS) of all sample points of rock mass is shown in Figure 3b. Blocks and circles represent the direction of maximum and minimum susceptibility axes, respectively. The sampling points have good consistency. The minimum susceptibility principal axis inclination of most samples is near the level and distributes along NE-SW direction, while the maximum susceptibility principal axis distributes along NW-SE direction. The maximum susceptibility axis of each sample is projected to Schmitt network (Figure 3c). It can be seen that the center of the minimum susceptibility spindle is located in the third quadrant, and its predominant direction is NE-SW. Another group is concentrated in NNE-SSW direction, but its density is small.

Table 1. Magnetic fabric data of the Keziletae Pluton.

| No. | Number | $K_m$ (μSI) | $L$ | $F$ | $P_j$ | $T$ | $K_{ma}(°)$ | $K_{md}(°)$ |
|----|--------|-------------|-----|-----|-------|-----|-------------|-------------|
| 2  | 7      | 2610        | 1.095 | 1.023 | 1.128 | -0.593 | 144/5       | 49.8/44     |
| 4  | 4      | 4340        | 1.085 | 1.040 | 1.128 | -0.334 | 142/8       | 41/54       |
| 6  | 2      | 176         | 1.037 | 1.032 | 1.072 | 0.131  | 289/3       | 197/32      |
| 10 | 5      | 1720        | 1.030 | 1.115 | 1.159 | 0.537  | 109/15      | 13/22       |
| 11 | 13     | 4770        | 1.250 | 1.149 | 1.445 | -0.217 | 257/2       | 166/27      |
| 15 | 6      | 243         | 1.029 | 1.049 | 1.081 | 0.245  | 300/44      | 190/20      |
| 16 | 4      | 230         | 1.020 | 1.046 | 1.070 | 0.381  | 278/9       | 185/17      |
| 29 | 3      | 5700        | 1.065 | 1.060 | 1.129 | -0.032 | 143/41      | 243/11      |
| 32 | 9      | 4640        | 1.048 | 1.067 | 1.119 | 0.176  | 130/21      | 230/24      |
| 33 | 8      | 2650        | 1.029 | 1.065 | 1.100 | 0.385  | 134/39      | 234/12      |
| 35 | 7      | 4590        | 1.032 | 1.048 | 1.083 | 0.224  | 97/28       | 2/8         |
5. Discussion

5.1 Magnetic fabric

The internal fabric of granite records the whole process from magmatic emplacement to metamorphic deformation, but the early fabric may be transformed by the later solid deformation. Therefore, in order to study the emplacement mechanism of rock mass by means of magnetic fabric method, the influence of late tectonic action on the transformation of primary magnetic fabric during emplacement should be excluded firstly [12]. The statistical results of magnetic anisotropy ($P_j$) of igneous rocks show that the magnetic susceptibility anisotropy $P_j$ value of magma flow origin is less than 1.2, while that of later tectonic changes is greater than 1.2 [13]. The $P_j$ values of most samples in Keziletage pluton are relatively small, with the peak frequencies ranging from 1.05 to 1.15. Only 7 samples such as G10 and G11 have $P_j$ values greater than 1.2. From the distribution of the minimum susceptibility principal axis of each point, the principal axis direction of the points with smaller $P_j$ are concentrated in NE-SW direction and mainly distributed in the interior of rock mass. The principal axes of points with greater $P_j$ value than 1.2 are concentrated in the NNE-SSW direction and mainly distributed in the southern and eastern boundary positions of the rock mass (Figure 4). Therefore, we suggest that the point with small magnetic anisotropy in the rock mass is formed when the rock mass is emplaced and cooled, retaining the original information of the magnetic fabric of the rock mass, and the NE-SW principal stress reflects the main structural direction of the rock mass emplacement. The points with high magnetic anisotropy at the edge of the rock mass are reformed by faulting activities, and the magnetic mineral particles in the rock are rearranged. At this time, the magnetic fabric reflects the direction of tectonic stress in the later period [13-15] and the NNE-SSW principal stress probably reflects the later structural direction. The distribution of principal stress direction further reveals that the tectonic influence on the eastern part of the rock mass is stronger than that on the western part, while that on the southern part is stronger than that on the northern part.
Long-term observations station at RUOQ, KORL and LOBU near the Keziletage pluton show that the regional northward motion component is 1.060-1.033 cm/a and the eastward motion component is 0.136-0.664 cm/a [14]. The north-south movement rate is obviously stronger than the East-West movement rate, which reflects that the current tectonic principal stress in the region is mainly in the near SN direction. This conclusion is consistent with the direction of the NE direction tectonic stress that are revealed by the magnetic fabric at the edge of the Keziletage pluton. Since the influence of Cenozoic Himalayan movement on the central and Western China is far greater than that of Yanshan movement in scale and intensity, it is speculated that the direction of NNE-trending the principal stress may be formed in Cenozoic.

5.2 Paleozoic tectonic setting of Keziletage

The whole process of melting, separation, rising and emplacement of granitic magma is closely related to the tectonic evolution of the orogenic belt. The emplacement of massive granites in the orogenic belt often occurs in the late stage of collision orogeny. At this time, the major tectonic belts in the orogenic belt began to carry out large-scale horizontal displacement to regulate the mass of material and energy gathered by collision and compression, while the fault zone usually becomes the channel of magma ascension [12]. A large number of studies have shown that the Tarim blocks and the Yili-mid TianShan micro-plate collided eventually during the Late Carboniferous [15-17] and the TianShan tectonic belt is dominated by compression system at this time. After the collision, the Tarim blocks continued to subduct northward and entered the post-collision stage. At this time, the TianShan tectonic belt changed from compression to strike-slip, which results in a large number of strike-slip structures [18-20] with depth of influence reaching the lithosphere [21]. The magnetic susceptibility parameters of the Keziletage pluton show that the number of flattened ellipsoids is only slightly more than that of stretched ellipsoids, which indicates that compression is already weak in the tectonic environment of rock mass formation. From the plane combination characteristics of faults in the rock mass, the NE-trending extended fault system and the piedmont fault form a typical echelon strike-slip structural system, which is relatively old and belongs to the product of equilibrium adjustment after the main orogenic period. It has the characteristics of gradual transition from ductile strike-slip to ductile-brittle strike-slip. There are a large number of dike swarms formed during Permian in the vicinity of the Keziletage pluton, which represents that the eastern part of the South TianShan Mountains has changed from a collision compression system to a post-collision extension system [22-24]. Meantime, the NE-trending fault system becomes tense, which provides an ascending channel for the emplacement of intermediate-basic dikes. In summary, under the background of the regional tectonic transition from compressional to extensional, the Keziletage pluton may have emplaced along the Piedmont Keziletage fault in the Permian late-orogenic phase, and it is the product of the orogenic relaxation period. Although the magnetic susceptibility ellipsoid principal axis orientation in the middle of the rock mass generally shows the NE-SW compressive tectonic stress environment, the NE
compression of the Tarim blocks on the Yili-mid TianShan micro-plate has been relatively weak at this time.

6. Conclusions
(1) The distribution characteristics of the minimum susceptibility axis in the Keziletage pluton indicate that the rock mass was in NE-SW tectonic compression environment during Paleozoic emplacement, and the direction of the principal compressive stress was NE-SW. During this period, rock mass was simultaneously subjected to compression and strike-slip tectonics. In Cenozoic, influenced by the Himalayan movement, the edge of the rock mass was reformed by structure, and the main direction of the structure changed to NNE-SSW direction.

(2) Keziletage pluton was the product of the orogenic relaxation period. The NE compression of the Tarim blocks on the Yili-mid TianShan micro-plate has been relatively weak at this time and the regional tectonic background has transitioned from compressional to extensional.

We thank the Key Laboratory for Magnetism and Magnetic Materials of the Ministry of Education of Lanzhou University for assistance in the directional magnetic susceptibility of rocks measurement. Our deepest gratitude goes to the anonymous reviewers for their careful work and thoughtful suggestions that have helped improve this paper substantially.

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