Research Method for Dyke Swarms Based on UAV Remote Sensing in Desert Areas: A Case Study in Beishan, Gansu, China

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Abstract. The Beishan area of Gansu, China, is an arid desert area, and the surface rocks are well-exposed, creating excellent conditions for drone remote sensing geological mapping experiments. The magmatic rocks and metamorphic rocks in the Beishan area are widely exposed, and a large number of basic and acidic dykes have developed. The formation and distribution of gold deposits are closely related to the dykes. In order to explore the development rules of dykes in this area, a 20km² area in the Changliushui area of Beishan was selected as the target, and a set of methods for studying the dyke swarm using drones was formed and applied: Images were collected and high-resolution orthophotos and three-dimensional models were synthesized, combined with ground work, and finally remote sensing geological interpretation was performed, to obtain high-precision geological maps. Based on this, the dykes were identified in detail and divided into four phases. The strikes and dips information of the dykes was extracted, and it could be concluded that the dominance of the strikes of the dykes in the target area is NEE, and the inclination is nearly upright, while the length and thickness of dykes obey a skewed distribution. The application of the method not only provides more geological information, but also provides clues for the tectonic evolution and formation mechanisms of dyke swarms, indicates the prospecting direction of future gold deposits.

1. Introduction
Beishan, Gansu, China, is located at the intersection of three major plates—Siberia, Kazakhstan, and Tarim-North China Plate [1]—and is part of the Central Asian Orogenic Belt [2]. In the Beishan area, after multi-round orogenic movements, the magmatic activity is strong [3], and there are dyke swarms mainly composed of medium-basic dykes, which are large in number and widely distributed. The dyke swarm is closely related to the formation of gold deposits. Medium basaltic dykes are the product of lithosphere extension and crustal tension [4-7]. Vein rocks provide heat, provenance, and space for...
mineralization [8, 9]. Identifying the types, morphology, distribution, combination characteristics, genesis, and period of dyke swarms can provide rich information for regional magma and tectonic evolution, and have guiding significance for prospecting [10-16].

Researchers have carried out detailed studies on the tectonic background, origin of the rock mass, metallogenic regularity, and ore-controlling factors in the Beishan area [1-3] [17-20]. Whilst they have carried out remote sensing geological interpretation, remote sensing alteration information extraction, and other work, interpretations of the dykes have only identified the approximate type and rough number, and the detailed distribution characteristics of the dyke swarm are not clear [21, 22]. Researchers have carried out studies on the petrology, petrography, mineralogy, and isotope dating of the Beishan area in Gansu. Based on the regional geological surveys of 1: 50,000 and 1: 10,000, the development of dyke swarm is mainly neutral and basic, and they are mainly distributed in the east-west direction. They are mainly formed during the Indosinian period [23].

UAV remote sensing technology is a new type of remote sensing technology developed with the popularization of drone technology. This technology can quickly collect high-resolution ground data in well-outcropped bedrock areas [24-27]. Photo modeling technology combined with the SFM method can generate a variety of data such as dense point clouds, orthophotos, and 3D models. It is widely used in digital terrain model reconstruction, fast digital mapping, and feature extraction [28-31]. This technology is gradually being widely used in surveying, mining, disaster and other fields [32-37]. The UAV image resolution can be at the level of centimeters or higher, which is much higher than that of satellite images, and this can greatly improve the accuracy of geological interpretation and promote the efficient extraction of structural information, which can effectively engage in highly refined geological research and automation [10,11,38-42]. UAVs equipped with specific sensors can also be used for thermal imaging, multispectral imaging, high-precision magnetic survey, etc., which can meet the needs of multi-source data for geological surveys [43-45].

At present, there are few research studies on the distribution law and development characteristics of the dyke swarms in the Beishan area. Limited by the mapping accuracy and mapping methods, it is difficult to fully and carefully understand the distribution of the dyke swarm and the relationship between different dykes in this area, which restricts our understanding of the genetic law of the dyke and its mineralization. Compared with the traditional mapping method, the UAV geological mapping acquisition image has no blank area, has a high resolution, and can comprehensively control the different scale of dykes in the study area, which is a favorable way to study the dyke swarm. However, a set of methods for this kind of approach has not been formed before. The Beishan area is located in the desert environment of Western China, with sparse vegetation and good surface rock exposure. It is a good area for UAV remote sensing geological research. In order to find out the spatial distribution law of the dyke swarm in the Beishan area, this paper selects the 20km² area of Beishan Changshuishui as the research area, and proposes a set of methods for interpreting the dyke by UAV. By collecting image data, and synthesizing orthophoto image and a three-dimensional model, this method determines the interpretation marks of the masses, fills in the geological map, interprets the dyke swarm in detail, and looks for the cross cutting relationship. The two-dimensional and three-dimensional occurrence information and distribution characteristics of dykes can be determined by dividing the stages. This method is suitable for arid desert areas with good rock outcropping and a suitable terrain height difference, and where the global desert area accounts for about 1/3 (48 million Km²) of the total land area. The study of dyke swarms in desert areas is of great significance to basic geology, structural evolution, prospecting, and exploration. This method has broad application prospects.

2. Study area
The Beishan area of Gansu is located in the Yujingzi-Liuyuan intracontinental rift zone in the Beishan terrestrial active zone of the Tarim Central-North Korean plate. The north and south margins of the rift zone are controlled by regional large-scale faults, showing a soothing wave shape, and the overall trend is east-west (Figure 1). The fold structure in this area is mostly accompanied by the development
of the east-west fault zone, and the axial direction is east-west or near-east-west. There are near-west compressive and torsional faults distributed in the area, and they are accompanied by two sets of torsional fault structures of north-south extension and north-west and north-east. The strata in the Beishan area include Sinian, Cambrian, Ordovician, Silurian, and the Devonian, but the fault structure in the area is developed, and frequent magmatic activities lead to scattered strata [46]. The magmatic rocks in the Beishan area can be roughly divided into three periods: early, middle, and Indosinian periods. Each magmatic period contains several intrusions [46]. There are a large number of rock masses, ranging in size, and most of them are rocky and wall-shaped. The lithology of the rock mass is complex, and rock masses such as porphyritic granite, orthogranite, feldspar granite, diorite, etc. were formed in the middle period of Western China [46]. The metamorphic crystalline basement is Archean plagioclase. The dykes are very developed and appear in groups [46-49], mainly including Indosinian diabase dykes, granite porphyry dykes, diorite dykes, and quartz veins.

The formation of intrusive rocks and veins in the Beishan area is accompanied by a tectonic movement curtain. The Beishan area in the late Paleozoic was a geodynamic environment with alternate plate opening and closing, and each closure was accompanied by crust-source granite magma activities. The orogeny at the end of the Permian period often continued into the Early Triassic and even the Jurassic [1]. During the Triassic period (Indo-Chinese period), affected by the resurgence of regional deep faults and the rise of internal heat flux in the continent, the paleo continental crust in this area began to show obvious signs of activation [49,50]. The Beishan area was in a collisional orogenic environment during the early-middle Triassic, and in the late Triassic-early Jurassic was in a post-collision environment [2].

![Figure 1](image_url)

**Figure 1.** Outline map of tectonic units in the Beishan area: I-1 Yamansu Hongshishan structural area; I-2 Xingxingxia Hanshan structural area; II-1 Gongpoquan Hongguoer structural area; II-2 Kumish Kawabulak structural area; II-3 Dunhuang Yumen structural area; II-4 Zhusling structural area; III-1 Alxa structural area.

3. Materials and Methodology
Field image data collection was conducted using the DJI Phantom IV pro of the quad-rotor drone. This model is equipped with a 1-inch 20 million effective pixel image sensor with an FOV of 84 ° and a high resolution of seven groups of eight glass lenses. The lens, has a focal length range of 8.8 mm / 24 mm and aperture f / 2.8—f / 11, with autofocus The data collection, processing and interpretation workflow are shown in Figure 2.
3.1. Data collection

The maximum flight altitude of the UAV’s non-restricted area was 500m. The higher the flying height, the shorter the time consumption, and the lower the amount of data, but the lower the resolution of the obtained image. The the flight height was lower, the image was sharper, but the time and data volume increased dramatically (Figure 3). After flight tests at different heights of 10, 25, 50, and 200m, and after calculating the accuracy and efficiency required for the work, the main flight height was selected to be 200m, and 50m flight heights were used for key areas. The resolution of the images collected at this height could reach about 6-7cm, which met the accuracy requirements of geological interpretation. The highest resolution of commercial satellite and aerial remote sensing can only reach a dm level, which then makes it difficult to meet the needs of fine geological interpretation (Figure 4).
Figure 4. Comparison of images from different data sources: (a) Landsat 8 (30 m resolution); (b) Google Earth (Maxar Technologies; 1 m resolution); (c) UAV remote sensing orthophoto image (25 m flight altitude; 0.8 cm resolution); (d) Google Earth (Maxar Technologies; 1 m resolution); (e) UAV remote sensing orthophoto image (200m flight altitude; 0.8cm resolution).

3.2. Data processing and interpretation

The acquired images were processed by Photoscan. Photoscan is excellent software launched by Agisoft Company to automatically generate high-quality 3D models based on images. After feature point matching, photo alignment, camera position calculation, feature point position calculation, three-dimensional encryption, the construction of a grid, the mapping of textures to obtain a three-dimensional model, and the further generation of DEM data and orthophotos were conducted.

Aimed at investigating the various geological contents of previous geological maps, combined with the obtained orthophotos and ground observations, interpretation signs were established. The geological bodies and structures in the orthophotos were interpreted with respect to the interpretation signs.

3.2.1. Interpretation of geological bodies and dykes. A summary of the orthophoto characteristics and interpretation signs of the plastids in various places was developed, as shown in Table 1:
Table 1. Interpretation signs of geological bodies

| Geological Bodies                  | Period[46] | Description                                                                 | Color                                      |
|-----------------------------------|------------|-----------------------------------------------------------------------------|--------------------------------------------|
| Diabase dykes                     | Indosinian | Straight, (thin) vein-like, and after weathering, sharp-shaped pieces, which are numerous and spread throughout the area | Black-dark green (Figure 5g)              |
| Granite porphyry dykes            | Indosinian | Thicker rounded veins                                                       | Reddish brown-flesh red (Figure 5f)       |
| Diorite porphytic dykes           | Indosinian | Vein-like production, similar to diorite veins, slightly lighter in color   | Gray-green-dark green (Figure 5a)         |
| Quartz veins                      | Indosinian | Straight, bright white, vein-like output, and common artificial mining traces | Bright white-off-white (Figure 5c)        |
| Plagioclase amphibole              | Archean    | Uneven low hilly terrain formed by weathering and erosion and cutting by flowing water | Off-white-dark gray-dark green (Figure 5g,h) |
| Porphyrific granite               | Mid Hercynian | It is lumpy, and the terrain is gentle after weathering and erosion         | Light gray-off-white with slight flesh red (Figure 5d,f) |
| Syenogranite                      | Mid Hercynian | Soothing, rounded low hills                                                 | Obvious light red-flesh red (Figure 5b,c) |
| Monzonitic granite                | Mid Hercynian | It has a gentle topography, it is severely eroded by flowing water, and a slight corrugated texture is visible on the surface | Off-white-pale red (Figure 5a)           |
| Diorite                            | Mid Hercynian | The terrain is slightly heavier                                            | Gray-green-light gray                     |
| Quaternary sediments              | Quaternary | Braided distribution along the water system, and a large number of camel thorns grow | Light yellow-brown yellow (Figure 5a)    |

3.2.2. Interpretation of fractures. Based on orthophotos, faults can be identified through indirect signs. Indirect interpretation signs include neatly displaced rock veins, straight gullies, and fault triangles, as shown in Table 2.
Table 2. Interpretation signs of fracture

| Fracture Interpretation Sign | Feature |
|-------------------------------|---------|
| Neatly distorted rock veins   | Straight rock veins suddenly rupture, with a neat cross section (Figure 5g) |
| Straight gutter              | The boundary of the gully or water system is not naturally curved, but is straight (Figure 5d) |
| Fault triangle                | The rock mass has a near-triangular cliff face (Figure 5b) |

Figure 5. Schematic diagram of orthophoto interpretation marks: (a) Monzonitic granite and diorite porphyrite vein; (b) syenogranite and fault triangle; (c) quartz vein cuts through a diabase dyke in two directions; (d) quartz vein cuts through a diabase dyke; (e) boundary between syenogranite and amphibolite; (f) porphyritic granite, with granite porphyry vein cuts through a diabase vein; (g) diabase vein, amphibolite, monzogranite, and faults; (h) the relationship between a granite porphyry dyke and two-stage diabase dyke.

According to the established interpretation marks, all of the orthophoto images in the test area were interpreted and clearly drawn, and a geological map of UAV orthophoto interpretation in the test area was obtained (Figure 6). Its coverage area is 20 square kilometers, and the mapping accuracy is higher than 1:10000.
3.3. Extraction method of dyke occurrence

3.3.1. Extraction method of dyke strike. In order to reflect the true shape of the dykes during interpretation, the dykes were filled with planar features (Figure 6), and the planar features were converted into polyline by ArcToolbox and dispersed into discrete line segments as the trend line of the rock vein boundary. The obtained strike line is the true boundary of the rock veins, and the data obtained by the ground workers using the compass to collect the strike direction of the veins are discrete and one-sided, so the strike data obtained by this method are more macroscopic and accurate.

Using the ArcGis calculate geometry tool, the start and end coordinates in the attribute table of the discrete line segments were filled in, and according to the trigonometric function relationship, calculate the data of 11,163 rock vein boundary strikes were calculated and exported to draw a rose map (Figure 7).
3.3.2. Extraction method of dyke strike and and dip angle elements. The landform in the north of the area is gentle, and there are a few hills in the south. The calculation of the yield is reliable with a large height difference. The hilly terrain is conducive to obtaining the dip angle data. The three point method was used to calculate the inclination angle. The three-dimensional model synthesized by Photoscan software was used to select the dyke on the hill, the top or bottom of the dyke, the starting point and the highest point at both ends to form a triangle plane, as well as to select the dyke plane with the triangle bottom angle $\alpha$ greater than 10 degrees to calculate the dip angle to reduce the error (Figure 8). Finally, 61 dykes that could be used for calculation were obtained, and the coordinates were obtained by Photoscan point selection tool. The trend and dip angle of the dyke have been calculated (Fig. 9). The dip angle obtained was generally consistent with the range of 75-88° measured in situ in the study of dikes and joints in the Beishan area [46,51].

![Figure 8. Selecting points in a 3D model.](image)

![Figure 9. Dyke pole map and Isodensity map in the Beishan area](image)

3.3.3. Extraction method of dyke length. The surface features of the dykes obtained by mapping are a reflection of the true shape of the veins, and the length of the axis is the true length of the dykes. The "Feature to Raster" tool in ArcToolbox was employed to obtain raster data for dyke swarms. The ArcScan module was then used to convert raster data into a binary distribution and scan for vectorization to generate the central axis of the dykes. The length of the central axis of the dykes was calculated using the attribute field. The statistical frequency shows that the frequency distribution of the length of the dykes conforms to the law of skewed distribution, and the length is concentrated in the range of 0-250m (Figure 10).
3.3.4. Extraction method of dyke thickness. The surface features of the dykes obtained by mapping were projected to WGS_1984_UTM_Zone_46N to obtain vector data that could be used to calculate the area. The area of each dyke was calculated using ArcGIS calculation geometry tools. The obtained area data were then divided by the length of the dykes to obtain the average thickness of each dyke. The frequency distribution of the statistics of rock vein thickness also conforms to the law of skewed distribution (Figure 11).

4. Results

4.1. Distribution characteristics of dykes

4.1.1. Distribution density. The dykes in the Beishan area are well developed and densely distributed. The ortho-granite body, plaque-like granite body, and periclastic granite body were all formed in the Late Permian[46], and the distribution of dykes is relatively sparse, with an average of 18 per km². The average number of veins in the Permian diorite is 21/Km². The oblique long-angle amphibole is a metamorphic crystalline basement of the Archean[46], the dykes in it are small and dense, with an average of 35 per km². The cause of this phenomenon is related to the mechanical properties and age of the rock mass. Acidic rocks are more rigid than medium-basic rocks, are more prone to brittle deformation under stress, and the formation of cracks is small and large, while medium-basic rocks are more tough, and tend to undergo tough deformation under stress. The cracks are numerous and small.
The oblique long-angle amphibole has experienced more tectonic movements and accumulated more joints and cracks than the Permian rocks in the area.

4.1.2. Length of dykes. The length of exposed dykes in the Beishan Changliushui area ranges from several meters to several hundred meters, mainly concentrated in 0-200m. The length distribution of some types of rock veins is regular. The length and frequency distribution of dykes according to the types of lithology found that the distribution of the diabase veins and granite (porphyry) veins conformed to the law of negative exponential distribution. The regularity is slightly worse (Figure 12).

![Figure 12](image)

(a) Histogram of frequency distribution of diabase dyke length; (b) Histogram of frequency distribution of diorite dyke length; (c) Histogram of frequency distribution of quartz vein length; (d) Histogram of frequency distribution of Granite (porphyry) dyke length

4.1.3. Thickness of dykes. The thickness of dykes in the Beishan Changliushui area ranges from tens of centimeters to several meters, mainly concentrated in 0-4m. The length and width ratio of rock veins is between 10 and 482, and the average aspect ratio is about 107. The thickness of some types of dykes is regular. Statistical analysis of the thickness frequency distribution of dykes according to lithological types shows that the thickness distribution of diabase dykes and diorite dykes conforms to the law of skewed distribution, and the main thickness is concentrated at 0-3.5m, but the main thickness is concentrated in 0.5-7m. The regularity of quartz vein thickness is slightly worse (Figure 13).
Figure 13. (a) Histogram of the frequency distribution of diabase dyke thickness; (b) histogram of the frequency distribution of diorite dyke thickness; (c) histogram of the frequency distribution of quartz vein thickness; (d) histogram of the frequency distribution of granite (porphyry) dyke thickness.

4.2. Formation stage of the dyke swarm

The dykes in the Beishan test area can be divided into four periods according to the cut-and-cut relationship of the veins interpreted in the drone orthophoto. The first stage includes the development of dark dykes dominated by diabase dykes. Granite porphyry dykes develop in the second stage, dark dykes dominated by diabase dykes emerge in the third stage, and quartz veins develop in the fourth stage.

The northwest-facing milky quartz vein cuts through the northeast-facing and northwest-facing diorite dykes (Figure 5c). In the plaque-like granite body, the northwestward quartz vein cuts through the northeastward diabase dykes (Figure 5d), so the formation of the diabase dyke occurred earlier than that of quartz vein.

The northeast-oriented granite porphyry vein cuts through the near-east-to-west direction pyrophytic vein, and it is inferred that the formation of the pyrophytic dyke occurred earlier than the granite porphyry dyke (Figure 5f).

Granite porphyry veins developed in the oblique long-angle amphibole body in the southeast of the Beishan study area cut through the older diabase, but at the same time were cut by the newer diabase. Based on our data, the diabase dykes (dark green dykes) in the study area can be divided into two periods (Figure 5h).

In previous geological reports [46], the relative activity sequence of Indosinian dykes in the Beishan area was as follows: granite (porphyry), fine-grained granite → diabase (pyrite) → pegmatite → amaranth, quartz vein, fluorite pulse.

The main differences can be summarized as two points:

1) There are differences in the types of dykes, and the types of dykes interpreted in this study are less numerous compared with previous reports [46]. The reason for this difference may be that within the range of 20km² selected by this study, dykes of various lithologies have not been completely exposed. For example, the porphyry veins and fluorite veins have not been exposed in the study area.
2) In this study, the diabase dyke was divided into two phases, but was presented as one phase in previous work [46]. The reason for this difference may be that there is a blank area between the traditional geologically mapped routes, and the evidence for the division of the glacier veins into two phases in Figure 5h is omitted.

4.3. Changes in the occurrence of dyke swarms

The dyke direction of the Beishan area is mainly near east–west direction, which is consistent with the general tectonic trend of the regional east-west to near east–west distribution. The statistical results of various dykes show that the dominant orientation of the dark dykes dominated by diabase is NEE. The granite dykes dominated by granite (porphyry) dykes are mainly NEE. The dominant orientations of the quartz veins are NEE and NWW (Figures 14).

![Figure 14](image_url)

**Figure 14.** (a) Rose diagram of diabase dykes; (b) Rose diagram of diorite porphyry dykes; (c) Rose diagram of granite (porphyry) dykes; (d) Rose diagram of quartz veins.
4.3.1. Variation of dip angle of dyke swarms. In the three-dimensional model obtained in this study, there are 61 undulating dykes that are suitable for being used in the three-point method to produce products, of which 58 are diabase veins, 2 are quartz veins, and 1 is a granite porphyry vein. Based on the pole maps and iso-density maps (Figure 9) obtained from these dykes, it was found that these poles were obviously symmetrically distributed at the two extremes. The direction of the rock veins in the Beishan area is basically stable in the direction of northeast to east, with an angle about 18°. The inclination is nearly upright, with slight, symmetrical, continuous oscillations in the range of 0-20° on both sides.

4.4. Changes in the occurrence of dyke swarms

The performance characteristics of various types of dykes in the study area are as listed in Table 3. It can be seen that the occurrence and performance characteristics of middle basic dikes are relatively concentrated. The granite (porphyry) dyke is shorter and thicker than the middle basic dyke.

Table 3. Performance characteristics of various types of dykes.

| Dyke Type               | Quantity | Length Range | Average Length | Thickness Range | Average Thickness | Aspect Ratio Range | Average Aspect Ratio | Main Strike |
|-------------------------|----------|--------------|----------------|-----------------|-------------------|-------------------|---------------------|-------------|
| Diabase dyke            | 703      | 19–1170 m    | 201 m          | 0.4–14 m        | 1.9 m             | 21–482            | 108.59              | 80–90°      |
| Diorite dyke            | 40       | 34–799 m     | 159 m          | 0.34–9.82 m     | 2.0 m             | 29–389            | 109.94              | 80–90°      |
| Quartz vein             | 32       | 44–1346 m    | 209 m          | 0.34–10.64 m    | 4.0 m             | 28–275            | 112.73              | 100–110     |
| Granite porphyry dyke   | 81       | 58–1165 m    | 142 m          | 0.96–8.41 m     | 4.9 m             | 14–253            | 102.19              | 70–80       |

5. Discussion

5.1. Large-Scale Geological Mapping

5.1.1. UAV Remote Sensing Provides Richer Geological Information. Geological maps of 1:10,000 only filled out 169 dykes[46], and drone orthophotos interpreted 863, representing not only an increase of 410.6% in quantity, but also the newly filled rock dykes provide important information for prospecting.

Because traditional manual mapping is based on discrete information collected by ground personnel along the field route, profile, and geological point, and UAV orthophotos are calculated based on continuous high-resolution photos, the geological map information interpreted by it is more comprehensive and accurate.

5.1.2. UAV Remote Sensing Restores the Real Boundary Shape of a Geological Body. It can be seen in the orthophoto that the true boundary of each rock mass is jagged (Figure 5e, Figure 15), not a smooth curve, as shown in previous geological maps[46]. The dykes are strips with different shapes, not a single lens, and the borders are dendritic rather than straight (Figure 5e, Figure 15) [46].
Figure 15. Comparison of the mapping effect for the syenite granite and amphibolite boundary. (a) Orthophoto interpretation map; (b) previous geological map [46].

5.1.3. **UAV Provides More Clues to Identify the Sequence of Geological Bodies.** The contact boundary between the ortho-granite and plagioclase amphibole bodies is jagged, and it is seen that ortho-granite veins intrude into the oblique-pebbles body from the boundary. 5e).

In addition, in the orthophoto image, a number of dyke combinations with cross cutting relationships have been found, which can be used for dyke stage division (Figure 5c, 5d, 5f, 5h). However, once this key evidence in the traditional geological survey method is not covered by the field route, it is difficult to clarify the sequence relationship between the dykes and the rock mass.

5.2. **Correlation of dykes and Mineralization.**

Many deposits in the Beishan area are closely related to veins, especially medium-acid veins and quartz veins. Beishan Nanjinshan Gold Deposit [52], Jinwozi Deposit [53], Xinghai Tungsten Polymetallic Deposit [54], Shijinpo Gold Deposit [55], Xinjinchang Gold Deposit [55], Beijin Gold deposit [55], Jinmiaojing gold deposit [56], Xiaoxigong gold deposit [56], etc. are all deposited in quartz veins or produced in association with quartz veins.

The distribution of acidic veins in the study area is concentrated in the northeast, and the distribution of quartz veins is slightly dispersed, showing two dominant directions of NE and NW. The deposits (points) formed in the quartz veins are closely related to the output (Figure 16). There are a total of four mines formed in the study area, all of which are formed in the NE-oriented medium-acid dykes, and three of which are in the quartz veins in the NE direction, one of which is in the diorite dykes in the NEE direction.
Figure 16. Relationship between ore spots and veins in Beishan test area

It can be seen that the hydrothermal fluid that forms the quartz veins of this period in the Beishan area contains gold ore components, and the NE–NEE quartz veins are favorable locations for the occurrence of ore bodies. A further exploration for gold deposits in the Beishan Changliushui area could be pursued in the NE–NEE quartz vein, and UAVs equipped with multispectral sensors could be used to extract mineral information and alteration information, which can further indicate the direction of ore prospecting.

5.3. Formation Mechanism of the Dyke Swarm
The morphological characteristics of the NEE oriented dykes in the study area are straight and fine veins and extend far, reflecting the compressive of the cracks filled by the veins due to compression stress (Figure 5f, 5h, Figure 16, Figure 17). This confirms that the Beishan area was in a collision orogenic environment in the early and middle Triassic, and was subject to intermittent north-south compression stress [2,46,49]. Because the dykes are distributed in a parallel direction from northeast to east, they are nearly upright, reflecting a single stress orientation in the area. The sparse north-south direction veins are slightly larger in width and shorter in length, which also proves that the direction of principal compressive stress is near south-south [2,46,49,52]. As shown in Figure 17, the thickness direction of granite porphyry veins indicates the direction of minimum stress. In addition, the late diabase dykes are still distorted, which also reflects the intermittent north-south compression that continues after the late diabase vein emplacement ends.
Subsequent research can be combined with isotopic dating, petrology, mineralogy, and microstructural methods of rock vein samples to further improve the formation and evolution of rock veins in the Beishan area and the change of Indosinian tectonic stress in the Beishan area. By combining the mechanical properties of the surrounding rocks, the magma source depth of the veins can also be estimated.

5.4. Prospects of method application
This method is suitable for areas with few people and hard work in the arid desert, where the rocks are better exposed, and the global desert area accounts for about 1/4 of the total land area, such as northwestern China, southern Mongolia, the Middle East, northern Africa, Western United States and other regions. UAV remote sensing is used to obtain high-resolution images of desert areas, synthesize orthophotos and three-dimensional models, and perform geological interpretation and the extraction of rock vein occurrences. These methods have good application prospects in the above areas. Which is of great significance in mineral exploration.

6. Conclusion
1) The method of using UAV remote sensing technology to study dyke swarms is put forward in this paper, which has a good effect on the study of dyke swarm occurrence, distribution and period characteristics in areas with good exposure and moderate terrain height difference.
2) UAV was used to collect images from the 20km² test area of Changliushui in Beishan, synthesize orthophotos and three-dimensional models, establish interpretation marks, and perform manual visual interpretation to obtain a more accurate and richer geology map and interpret more dykes.
3) The UAV remote sensing method is used in this paper to summarize the distribution characteristics of dyke swarms in the Beishan area and divide it four periods, as well as the length and thickness distribution.
4) The UAV remote sensing method was used to extract the occurrence information of the dyke swarm, and the rose maps of the strike, iso-density and pole were drawn, and the preferred orientation of the dykes in the Beishan area was: the strike was NEE, and the dip angle was nearly upright.
5) The method provides clues for prospecting and evidence for structural evolution, and has a good application prospect.

Acknowledgments
The work is supported by the Geological Survey Project of the China Geology Survey (DD20160050). We sincerely appreciate all the reviewers for their contribution of time and comments.

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