臺灣雪山山脈變形與剝蝕機制關係之研究

Study of the Relationship between Deformation and Exhumation across the Northern Hsuehshan Range, Taiwan

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Motivation

Paleomagnetism of polarity reversal is the first evidence of seafloor spreading and makes an important foundation of Plate Tectonics. Such as different color strips in the figure 1 like what we see currently in the Atlantic Ocean. This really inspires us: Could we study the folding deformation of rock formations via the Paleomagnetism?

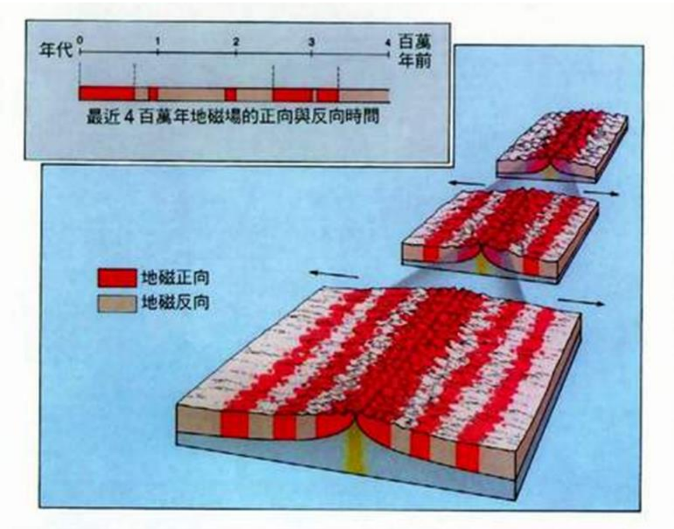

Figure 1. Paleomagnetism of polarity reversal of seafloor spreading.

As weathering or metamorphism can form secondary magnetic minerals, the natural remanent magnetization (NRM) recorded by rocks is to sum up primary and secondary magnetic vectors. In order to obtain clear magnetic vector, this study will use thermal demagnetization to separate magnetic vectors. Fold test (Figure 2) show 2 different cases. Case 1 is folding deformation before maximum metamorphic temperature. Case 2 is folding deformation after maximum metamorphic temperature. Fold test of remanent magnetization directions of rocks can separate these 2 cases.

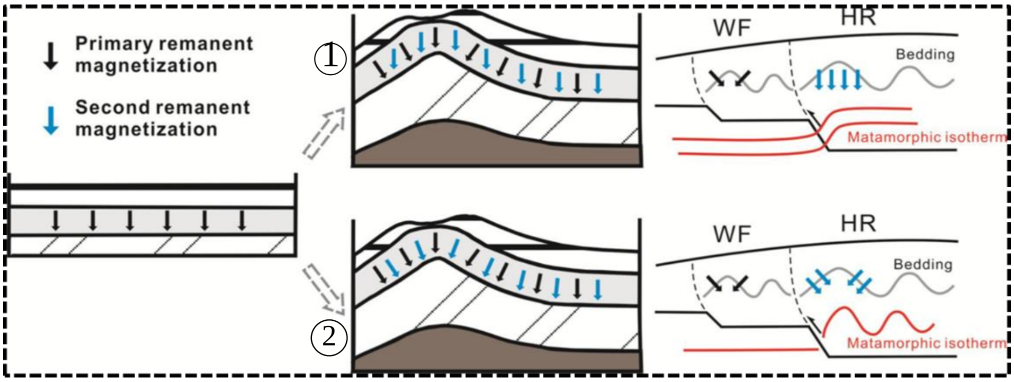

Figure 2. Fold Test. Case 1 is folding deformation before metamorphic temperature. Case 2 is folding deformation after metamorphic temperature. Fold test of remanent magnetization directions of rocks can separate these 2 cases.

Xiao-Jun Peng(2015) run thermal demagnetization with 30-40℃ interval. The result of remanent magnetization of 270-320℃ decreases quickly and they can be treated as reasonable magnetic vectors. In the stereonet (Figure 3) , magnetic vectors are concentrated in the folding stage with reversal polarity, suggesting folding deformation happened before overprint of maximum metamorphic temperature as case 1 in the Figure 2. Using previous dating results, the age of 320℃ can be estimates as 10.4Ma. However, global magnetic pattern shows that it should be normal polarity but Peng's result is reversal polarity. One possibility is that temperature interval with 30-40C in Peng's experiment was too large so that she could not determine clear magnetic vectors. HOW we can solve this problem?

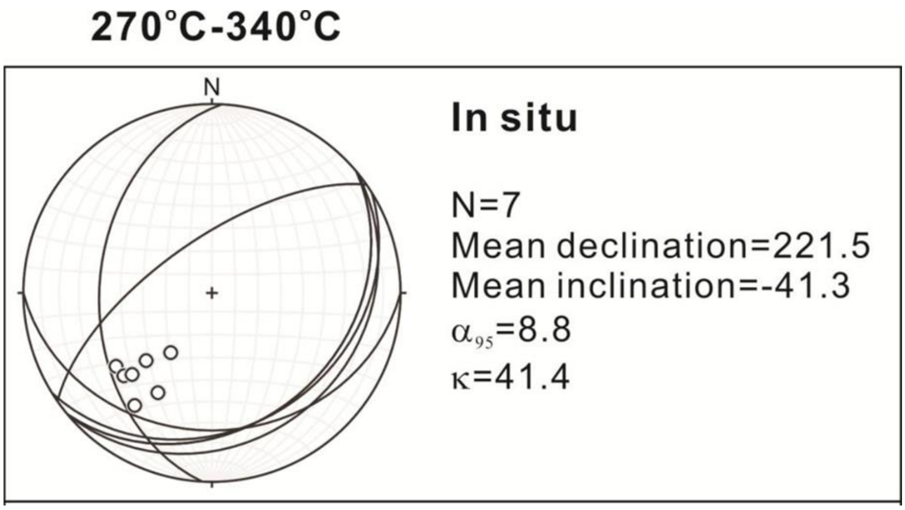

Figure 3. Stereonet Plot. Magnetic vectors are concentrated in the folding stage with reversal polarity.

Therefore, my motivation is decreasing the thermal demagnetization interval to around 5 degrees and finding better magnetic vectors and ages. Such as in Crouzet's paper (2001) of Experimental evaluation of thermal recording of successive polarities during uplift of metasediments, authors attempted to find better small magnetic vectors with only a few degrees heating. The results correlate with global polarity timescale quite well.

Methods

In order to evaluate the interrelationship between maximum metamorphic temperature and deformation for Taiwan mountain belt, we collected samples of low-grade metamorphic rocks from the Northern Cross-Island Highway. Thermal demagnetization will help us understand the sequence between deformation and metamorphism. Thermal magnetic experiment and hysteresis experiment can help us identify the magnetic mineral. And the deformation can be inferred from the study of magnetic susceptibility anisotropy.

Study Area

My amples came from Chungling anticline and Chatienshan anticline along the Northern Cross-Island Highway. The Figure 4 is a geology map.

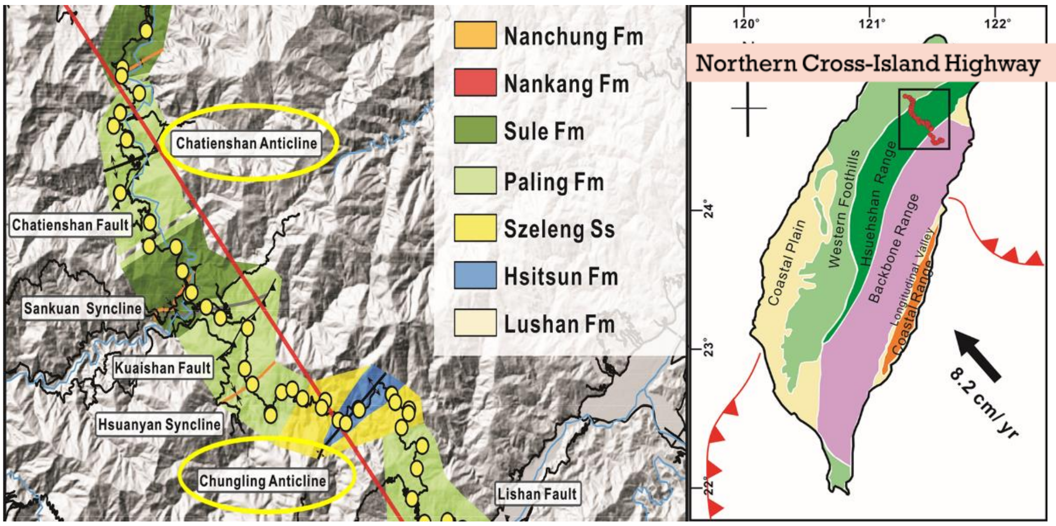

Figure 4. Geology map.

Introduction & Experiments

Before doing experiments, I cut the samples into standard size. It's a cylinder that both its diameter and height are 2.2 centimeters.

Thermal magnetic experiment

Figure 5 is the plot of temperature with magnetic susceptibility. This is the result

I did. We can see that magnetic susceptibility increase and then decrease during heating process. It means the existence of magnetic mineral. The curie temperature of magnetite is 575 degrees. So we think there is magnetite in this sample of Chatienshan anticline. Step 1 of thermal magnetic experiment is to mill the samples into powder. The Step 2 is to put the powder into the thin tube and put the tube into the instrument. The instrument will heat up the samples and then cooling down, and measure the susceptibility of the samples during the time. And we would know which type of magnetic mineral may exist in the samples via observing the change of magnetic susceptibility with temperature.

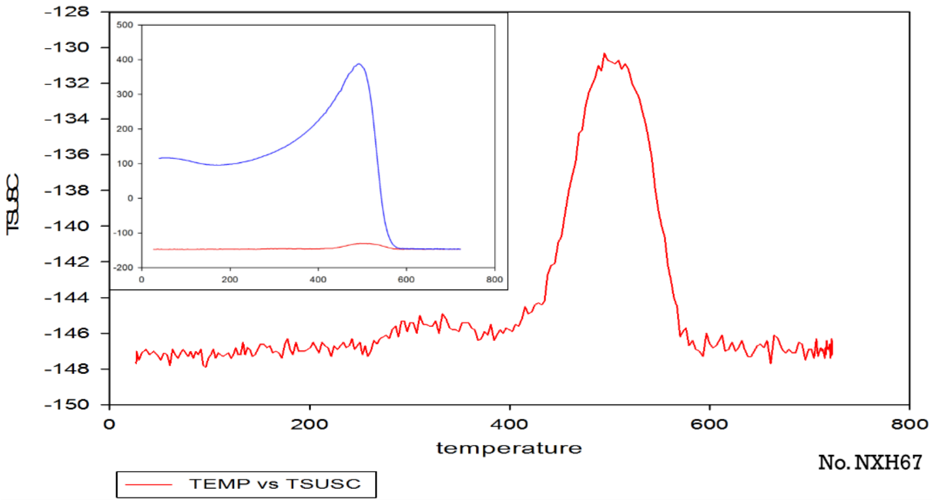

Figure 5. The plot of temperature with magnetic susceptibility. Red curve indicates heating, and blue curve denotes cooling.

Hysteresis experiment

If the material contains magnetic mineral, we will see hysteresis phenomenon. In the Figure 6, red path is hysteresis loop. There is an eye's shape in the middle, and it means the existence of magnetic mineral. The larger the eye's shape, the smaller the magnetic grain, the clearer the hysteresis phenomenon.

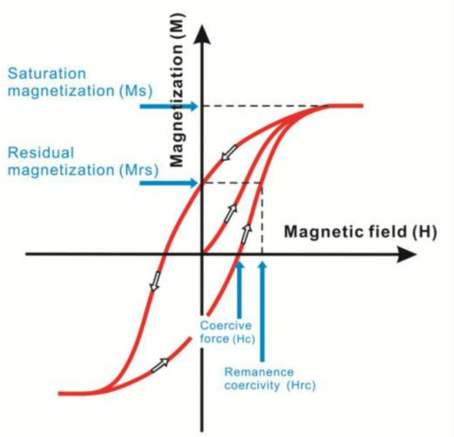

Figure 6. Hysteresis loop. Eye's shape in the middle means the existence of magnetic mineral.

The two diagram (Figure 7) is original hysteresis loop and another is regulated by the slope. We can see obvious eye's shape in the picture. It means the sample has ferromagnetic mineral. The smaller the grain of the mineral, the clearer the hysteresis phenomenon.

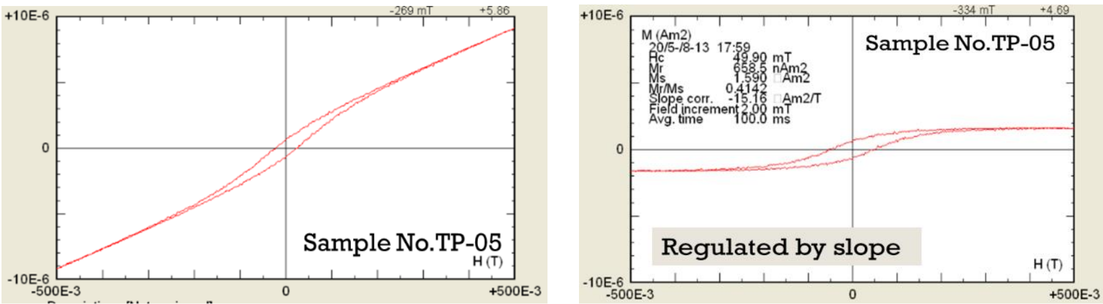

Figure 7. Original hysteresis loop and another is regulated by the slope.

Anisotropy of magnetic susceptibility (AMS)

When an additional magnetic field H is applied, magnetic mineral will produce a magnetization M. The coefficient between additional magnetic field and magnetization is magnetic susceptibity k. Figure 8 is magnetic susceptibility ellipsoid. We define K1≥K2≥K3. K1 is usually perpendicular to compression direction. Based on principal values of magnetic susceptibility ellipsoid, we can obtain deformation data. Experiment for anisotropy of magnetic susceptibility is measuring the of each sample in three orientations and getting the values K1, K2, K3, the average of magnetic susceptibility (Km), Anisotropy(P), Lineation(L), Foliation(F), and etc.

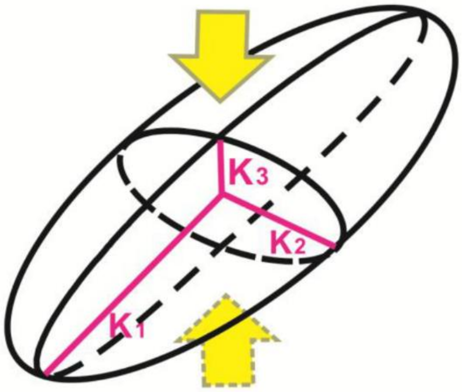

Figure 8. Magnetic susceptibility ellipsoid. K1≥K2≥K3

Thermal Demagnetization

Magnetic mineral will be removed its magnetism after heating over its Curie temperature. Figure 9 is also the result of my thermal demagnetization. We could see the curve falls down quickly in a small interval of temperature. That means some remanent magnetization recorded by specific magnetic mineral has been removed.

In the experiment, we put the samples into heating ovens and heat them to specific temperature, then cool them down. We should wait until it cools down to the room temperature and then measure NRM and magnetic susceptibility. The way of measuring NRM is to put the samples on convey belt, and the samples will be moved into instrument for measurement. And for the measurement of magnetic susceptibility, we put sample in the place where the arrow point at in the Figure 10, then the sensor will show the value. It totally took about 2 hours heating, cooling, and measuring for each temperature.

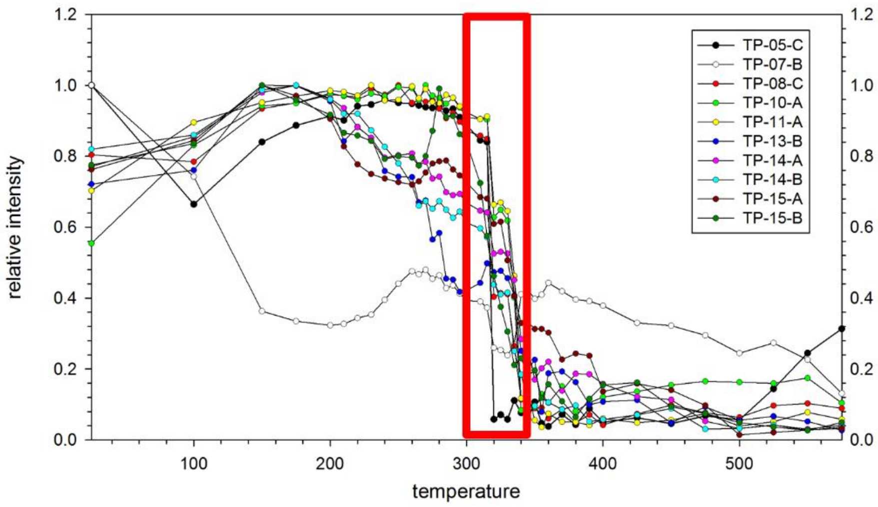

Figure 9. Relative Intensity with Temperature. The curve falls down quickly in a small interval of temperature. That means some remanent magnetization recorded by specific magnetic mineral has been removed.

Figure 10. The instrument for the measurement of magnetic susceptibility. We put sample in the place where the arrow point at, then the sensor will show the value.

Results and Discussions

Figure 11 is stereonet plot of K1, K2, andK3 of Chunling anticline. Based on K3 orientation, it indicates the NW-SE compression direction as red arrows shown.

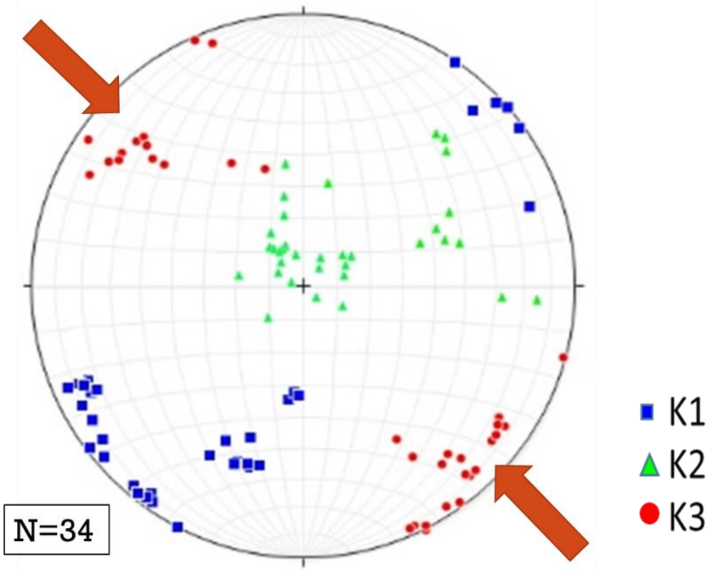

Figure 11. Stereonet plot. It indicates the NW-SE compression direction.

Figure 12 is Flinn diagram that indicates deformation pattern of ellipsoid. If k1 is larger than k2 & k3, it's cigar shape. If k1&k2 are larger than k3, it is disc shape. Look at figure 13, below the line is cigar-shaped, and above the line is disc-shaped. My data show most samples are disc shape, consistent with Peng's results. Because they derived from low-grade meta-sedimentary rocks that inherently have a planar fabric.

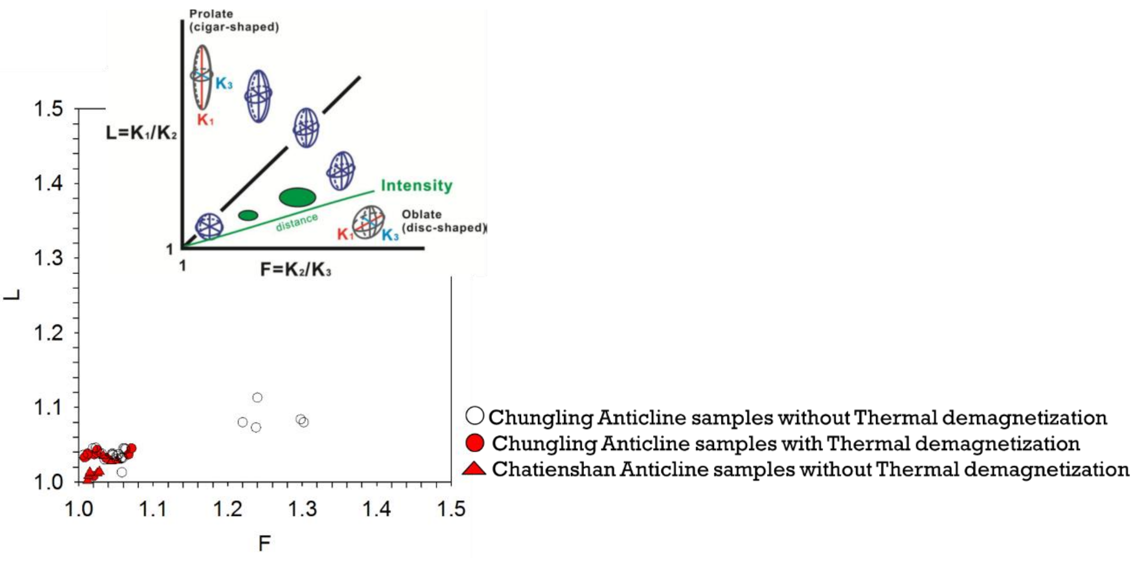

Figure 12. Flinn diagram. Indicate deformation pattern of ellipsoid.

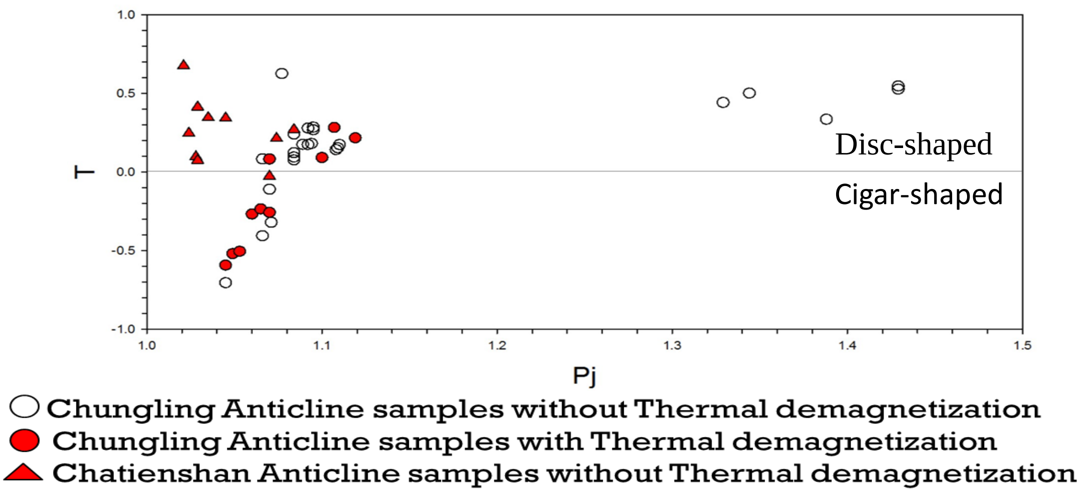

Figure 13. T-Pj Plot.

Figure 14 is the result of thermal demagnetization. This diagram (Figure 14-a) can show the direction of declination and inclination of magnetic field after every heating step. We try to find any recorded direction from such data. Look at the diagram in the right hand (Figure 14-b) , the remanent magnetization fall to zero point by degrees from 380 to 575 ℃. It shows one of recorded direction.

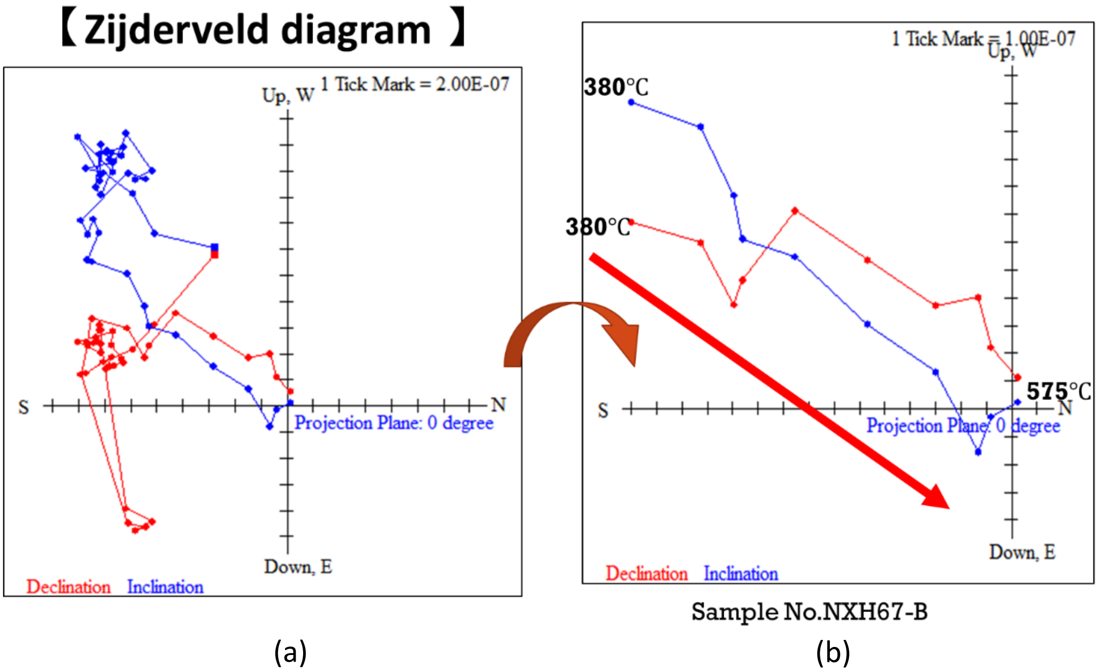

Figure 14. Zijderveld Diagram. (a) This diagram can show the direction of declination and inclination. (b) It shows one of recorded direction.

Because most samples' intensities are too low such as ten to the minus six to the minus seven (10^{-6}~10^{-7}), almost the detect limitation of instrument, the signal are not so reliable. So, if we need to run experiments, we need to use better instrument with detect limitation of 10^{-8}~10^{-9} and also keep samples in the better shielding environment. Due to reliability is not so good, we couldn't find the magnetic polarity we expected.

Though we didn't get the things we want, we still could get some information from the experiments. Figure 15 is the intensity after normalizing. Relative intensity of most samples declined rapidly around 300-340 degrees , and exactly the Curie temperature of pyrrohtite is about 320 degrees. So we think it's pyrrohtite. The result is consistent with Horng's result and also consistent with previous estimation of maximum metamorphic temperature (330°C). Also, there is a jump, it might reflect 2 types of pyrrhotites. Since magnetic susceptibility changes when temperature researched 700°C, we interpreted that 10% of NRM is recorded by Ti-magnetite. Because high curie temperature of Ti-magnetite, Ti-magnetite might recode primary remanent magnetization. It can be tested by future study.

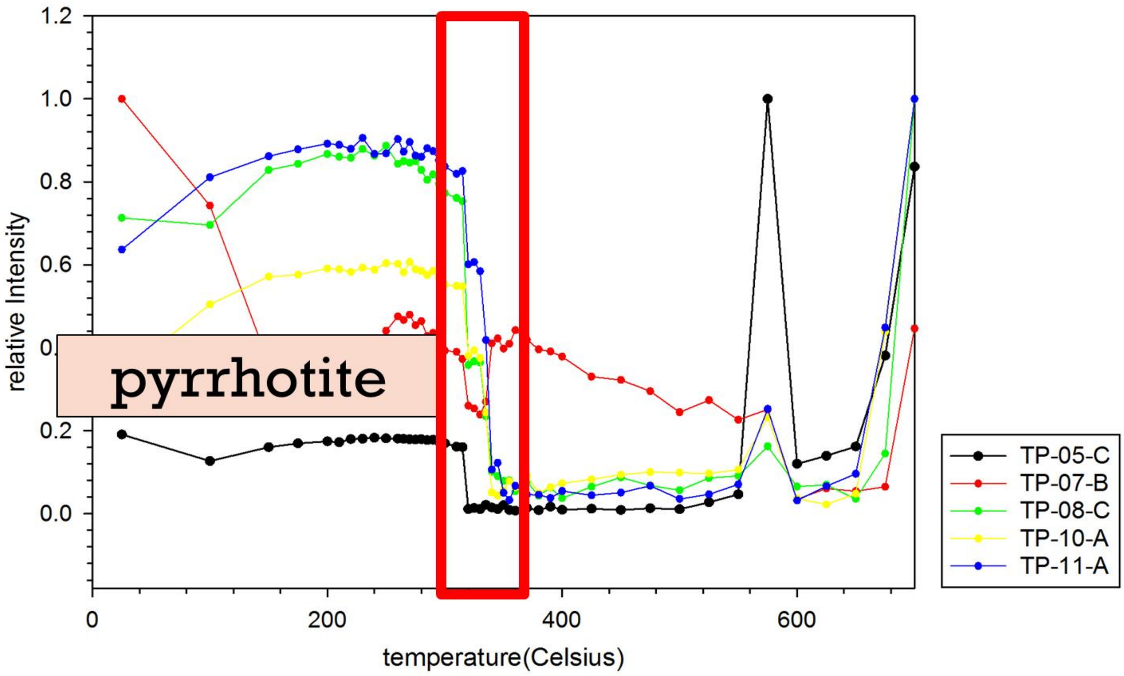

Figure 15. Intensity after normalizing. Relative intensity of most samples declined rapidly around 300-340 degrees , and exactly the Curie temperature of pyrrohtite is about 320 degrees.

Conclusions

(1) The compression direction is northwest to southeast.
(2) Most samples display an disc-shaped magnetic symmetry, because they derive from low-grade meta-sedimentary rocks that inherently have a planar fabric.
(3) Because of the low intensity of most samples, nearly same to the detect limitation of instrument. We think that it's not reliable. We should use better instrument and keep samples in the better shielding environment.
(4) We confirm the existence of pyrrhotite in the Chungling Anticline, consistent with previous estimation of maximum metamorphic temperature.
(5) We interpreted that 10 % of NRM is recorded by Ti-magnetite, and it might record primary remanent magnetization.