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SOME EXPERIMENTAL RESULTS OF ANALYZING QUANTITATIVE CORRELATION OF FRACTURE FREQUENCY DISTRIBUTION: CASE STUDY IN QUANG NINH PROVINCE, VIET NAM

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Abstract: This paper presents the experimental results of analyzing the quantitative correlation of fracture distribution at 10 survey sites on the Co To-Thanh Lan islands, Quang Ninh province, Viet Nam. The obtained results show that most fracture correlation coefficients are over 0.80. The high correlation values among the survey sites reflect well the geodynamic conditions of the tectonic activity phases. These results confirm the significance of the correlation method in analyzing the structural geology and geotechnics.

Key words: fracture distribution; stereonet window; correlation coefficient; survey sites; lower hemisphere

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ЭКСПЕРИМЕНТАЛЬНЫЕ РЕЗУЛЬТАТЫ АНАЛИЗА КОЛИЧЕСТВЕННОЙ КОРРЕЛЯЦИИ ЧАСТОТЫ РАСПРЕДЕЛЕНИЯ ТРЕЩИНОВАТОСТИ НА ПРИМЕРЕ ИЗУЧЕНИЯ ПРОВИНЦИИ КУАНГНИН (ВЬЕТНАМ)

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Аннотация: Представлены экспериментальные результаты анализа количественной корреляции частоты распределения трещиноватости по десяти изученным участкам на островах Ко-То и Тань-Лан в провинции Куангнин (Вьетнам). Полученные результаты показывают, что большинство коэффициентов корреляции трещиноватости превышают 0.80. Высокая корреляция значений по изученным участкам хорошо отражает геодинамическую обстановку на этапах тектонической активности. Результаты подтверждают значение метода корреляция для анализа структурной геологии и геотехнических работ.

Ключевые слова: распределение трещиноватости; стереоокно; коэффициент корреляции; места съемки; нижняя полусфера

1. INTRODUCTION

A structural unit of rock massis is characterized by the parameters of density, orientation, and spacing of fractures and faults. In some previous studies on geotechnical engineering, the division of the structural units was conducted by using the method of quantitative correlation of fracture distribution [*Kulatilake et al., 1990; Martin, Tannant, 2004; Miller, 1983*].

Recently, the method of quantitative correlation has been also used for analyzing the frequency of fracture orientation distribution, which occurred along the tunnel and the borehole, to identify structural domain boundary [*Quoc Phi Nguyen et al., 2012; Truong Thanh Phi et al., 2015; Truong Thanh Phi, Quoc Phi Nguyen, 2015*]. The results from these studies provide a useful tool to support determining structural domains and delineating structural domain boundaries.

In this study, we try to use the above-mentioned method to analysis fracture distribution at 10 survey sites on the Co To-Thanh Lan islands, Quang Ninh province, Viet Nam, to confirm its effectiveness for studying structural domains and/or fault zones.

2. METHODOLOGY

This study uses the correlation method to calculate a correlation coefficient of fracture frequency distribution between two stereonet windows of two different survey sites. The calculation is carried out based on the number of fracture poles in each cell on stereonet window plotted on the lower hemisphere projection (Fig. 1).

Figure 1 illustrates the fracture frequency distribution on two stereonet windows. After plotting fracture orientations of each survey site on the stereonet window in Figure 1, the calculation of fracture correlation coefficient between two stereonet windows is carried out using Equation 1:

$$R(x,y) = \frac{\sum_{i=1}^{n}(x_i-\bar{X})(y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{X})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{Y})^2}} \quad (1)$$

where (x_1, y_1), (x_2, y_2), …, (x_n, y_n) are n pairs of observations of a random sample of two random variables X and Y; $\bar{X}$ and $\bar{Y}$ are the average values of the fracture numbers of two stereonet windows; x_i is the fracture number that appears in each cell of the first stereonet window; and y_i is the fracture number that appears in each cell of the second stereonet window. The values of x_i and y_i may occur within 324 cells in each stereonet window if each cell of it is divided into10°×10° according to the values of dip direction and dip angle.

The correlation coefficient expresses the strength of the association between the two variables from two stereonet windows. These values always lie within –1…+1 and are independent of the magnitude of the variables. If the correlation coefficient is –1, it means perfect negative correlation; if the correlation coeffi-

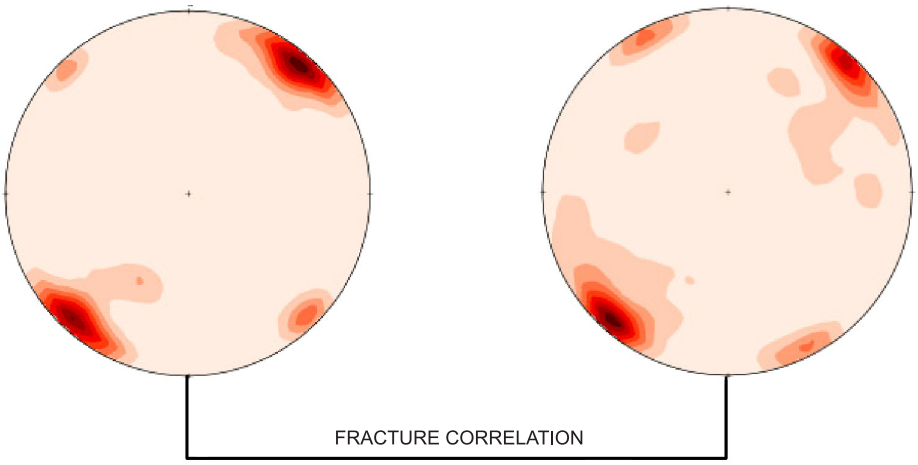

Fig. 1. Stereonet contour poles of two survey sites (two stereonet windows).

Рис. 1. Стереоконтурные полюсы по двум участкам съемки (два стереоокна).

cient is 0, it means no correlation; and if the correlation coefficient is 1, it means perfect positive correlation.

3. Results

The data collection was conducted at 10 survey sites on the Ordovician-Silurian sedimentary rocks (O_3-S*ct*$_1$ and O_3-S*ct*$_2$) of the Coto formation on the Co To – Thanh Lan islands [*Geological and Mineral Resources Map..., 1999*], including the parameters of fracture orientation (Fig. 2 and Table 1).

The Co To-Thanh Lan islands are located in the north of Tonkin Gulf, Quang Ninh province, Viet Nam. The Coto formation on the two islands mainly composes of slightly metamorphic rocks (sandstone, siltstone and claystone), which were formed in the deep-sea environment [*Van Tri Tran et al., 1972*]. The geology of the area was studied by [*Dovzhikov et al., 1965; Fuchs, Saladin, 1882; Van Tri Tran et al., 1972*]. Before, the strata in this area was considered as Triassic [*Patte, 1927*] or Neogenic [*Dovzhikov et al., 1965*]. Later, the rocks were determined as Ordovician–Silurian based on Graptolite fossil [*Van Tri Tran et al., 1972*].

The study area has been strongly affected by several phases of tectonic activity that deformed the rocks significantly in term of folding and fracturing. However, the purpose of this study is to calculate the fracture correlation distribution, therefore only fracture orientation is considered.

The fracture numbers for all the survey sites are given in Table 1.

The quantitative calculation of fracture distribution is conducted according to their frequency at eight different survey sites on the Ordovician-Silurian sedimentary rocks (O_3-S*ct*$_1$ and O_3-S*ct*$_2$) of the Coto formation on the Co To island. The results of quantitative analysis of fracture distribution for different survey sites according to the pairs of stereonet windows are shown in Figure 3.

Similarly, the quantitative calculation of fracture distribution is also conducted according to their frequency for two survey sites on the Ordovician-Silurian sedimentary rocks (O_3-S*ct*$_2$) of the Coto formation on the Thanh Lan island and between the Co To and Thanh Lan islands (Figs. 4 and 5).

The results of calculating the fracture correlation coefficients for different survey sites on Co To, Thanh Lan islands and the resume stereonet for these islands are shown in Table 2.

The results in Table 2 show that most correlation values are over 0.80, corresponding to about 70 % of the total number of fractures in the NW-SE direction. These values are well reflected on the map in Figure 6.

4. Discussion

The rocks on the Co To-Thanh Lan islands belong to the Co To formation, O_3-S_1*ct* and O_3-S_2*ct* [*Van Tri Tran, 1972*]. They were a deep sea formation and underwent different stages of ductile and brittle deformation. Due to ductile deformation with the NE-SW-trending compression, folds with the NW-SE axis were formed (Figs. 7 and 8). Continuous NW-SE-trending compression formed the fracture system on the Co To-Thanh Lan islands and the adjacent area. Extensional fractures are abundant on the islands and mainly have the NW-SE direction (Figs. 9 and 10). The similarity of the fracture distribution among the survey sites shows high correlation values. These results suggest that the fractures formed in the same geodynamical conditions (Figs. 9 and 10).

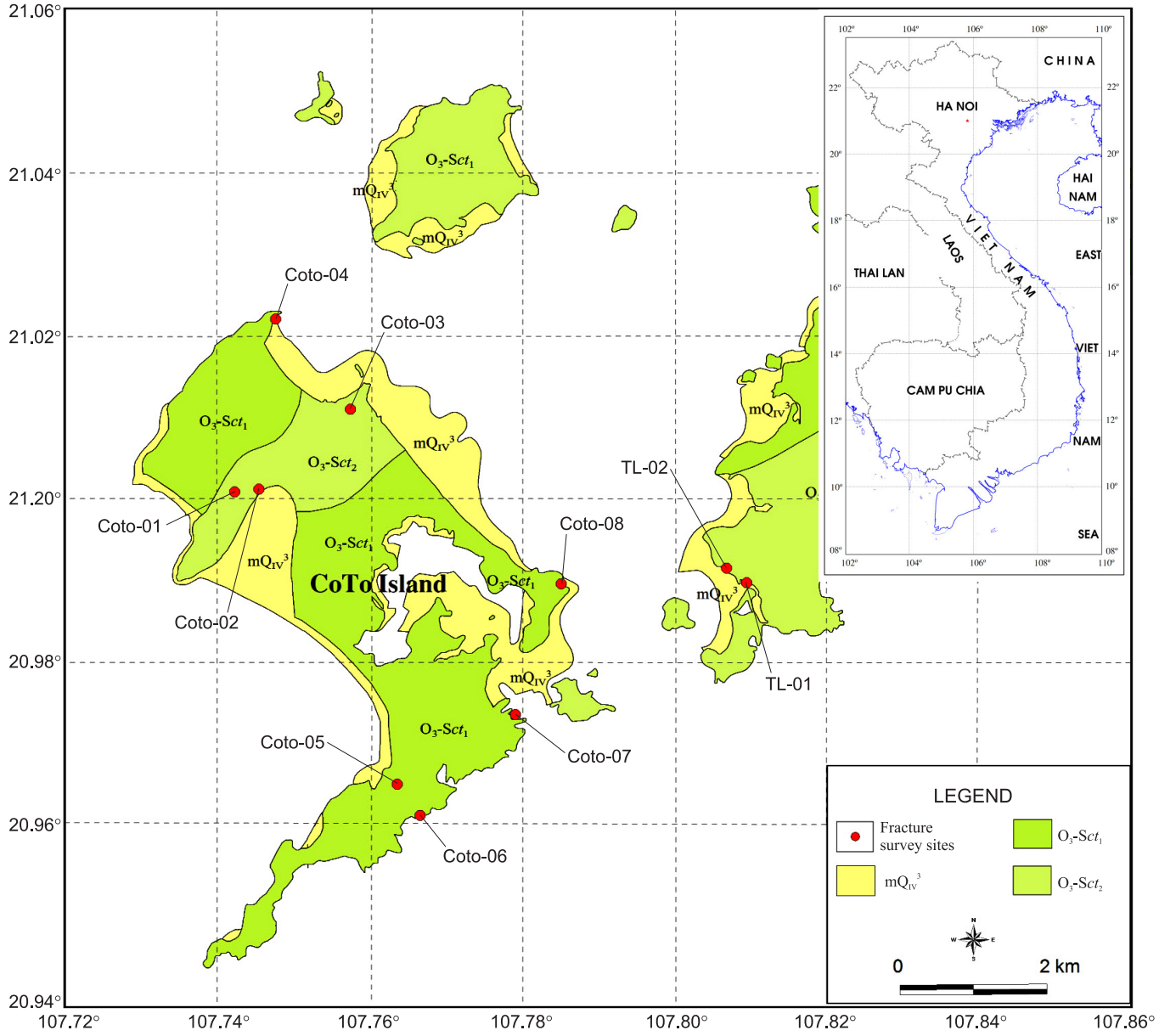

Fig. 2. Location map of survey sites on the Co To-Thanh Lan islands.

Рис. 2. Карта местоположения участков съемки на островах Ко-То и Тань-Лан.

T a b l e 1. **Locations of survey sites on the Co To-Thanh Lan islands, and their fracture numbers**

T а б л и ц а 1. **Координаты изученных участков на островах Ко-То и Тань-Лан и количество трещин на участках**

No.	Survey sites	Sub-meridian	Sub-horizontal	Geological age	Fracture number
01	Coto-01	107° 44' 27.9"	21° 00' 11.4"	O_3-Sct_2	203
02	Coto-02	107° 44' 39.4"	21° 00' 12.4"	O_3-Sct_2	141
03	Coto-03	107° 44' 08.6"	21° 01' 27.7"	O_3-Sct_1	206
04	Coto-04	107° 45' 23.3"	21° 00' 47.1"	O_3-Sct_2	219
05	Coto-05	107° 45' 42.2"	20° 58' 00.5"	O_3-Sct_1	137
06	Coto-06	107° 45' 52.9"	20° 57' 46.5"	O_3-Sct_1	124
07	Coto-07	107° 46' 38.7"	20° 58' 30.5"	O_3-Sct_1	174
08	Coto-08	107° 47' 01.2"	20° 59' 28.2"	O_3-Sct_1	188
09	TL-01	107° 48' 19.4"	20° 59' 33.8"	O_3-Sct_2	120
10	TL-02	107° 48' 28.9"	20° 59' 27.2"	O_3-Sct_2	122
Total number of fractures					**1634**

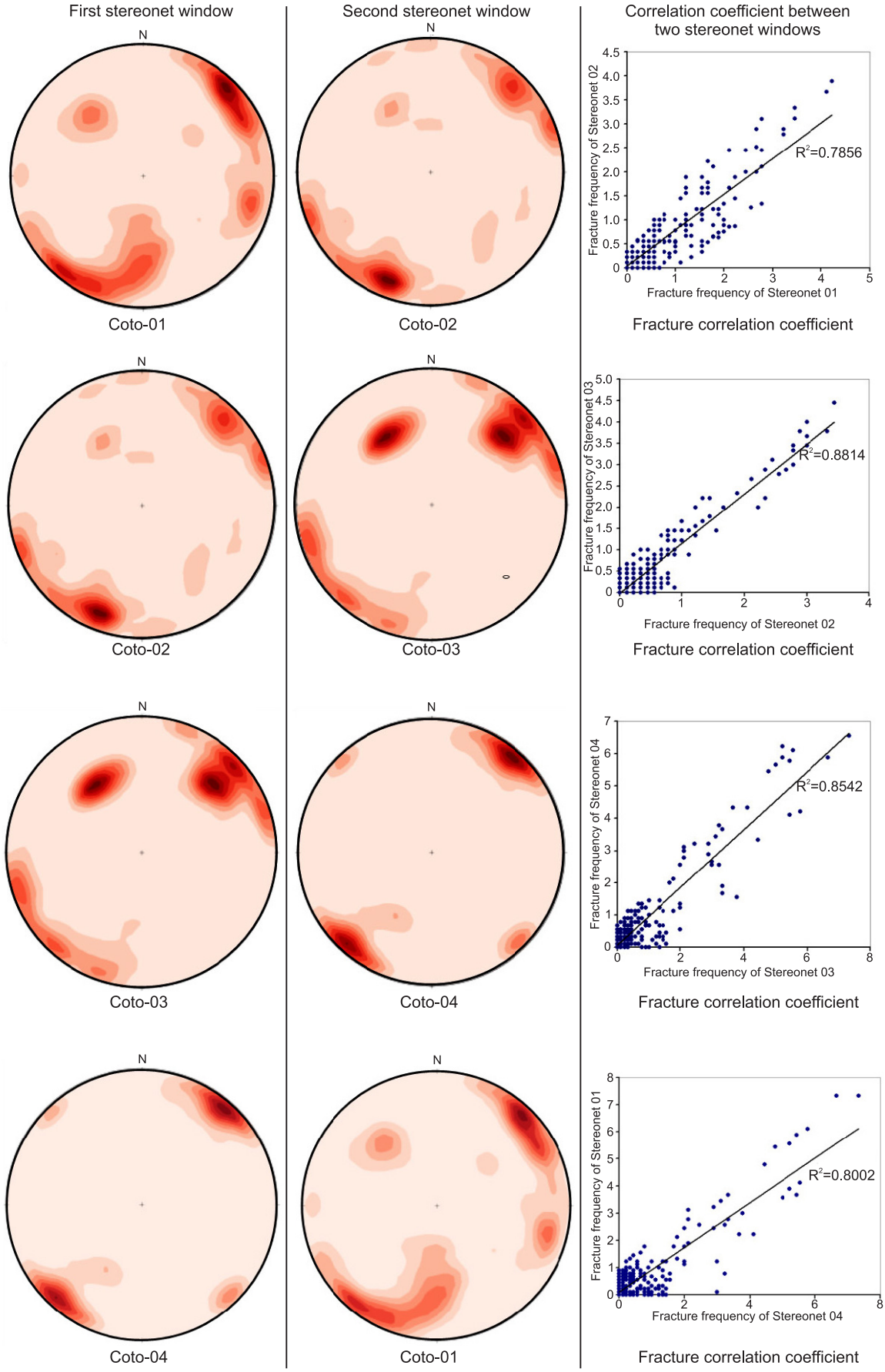

Fig. 3. Lower hemisphere projection of fracture poles and their correlation coefficient on the Co To Island.

Рис. 3. Нижняя полусфера проекции полюсов трещин и их коэффициент корреляции на острове Ко-То.

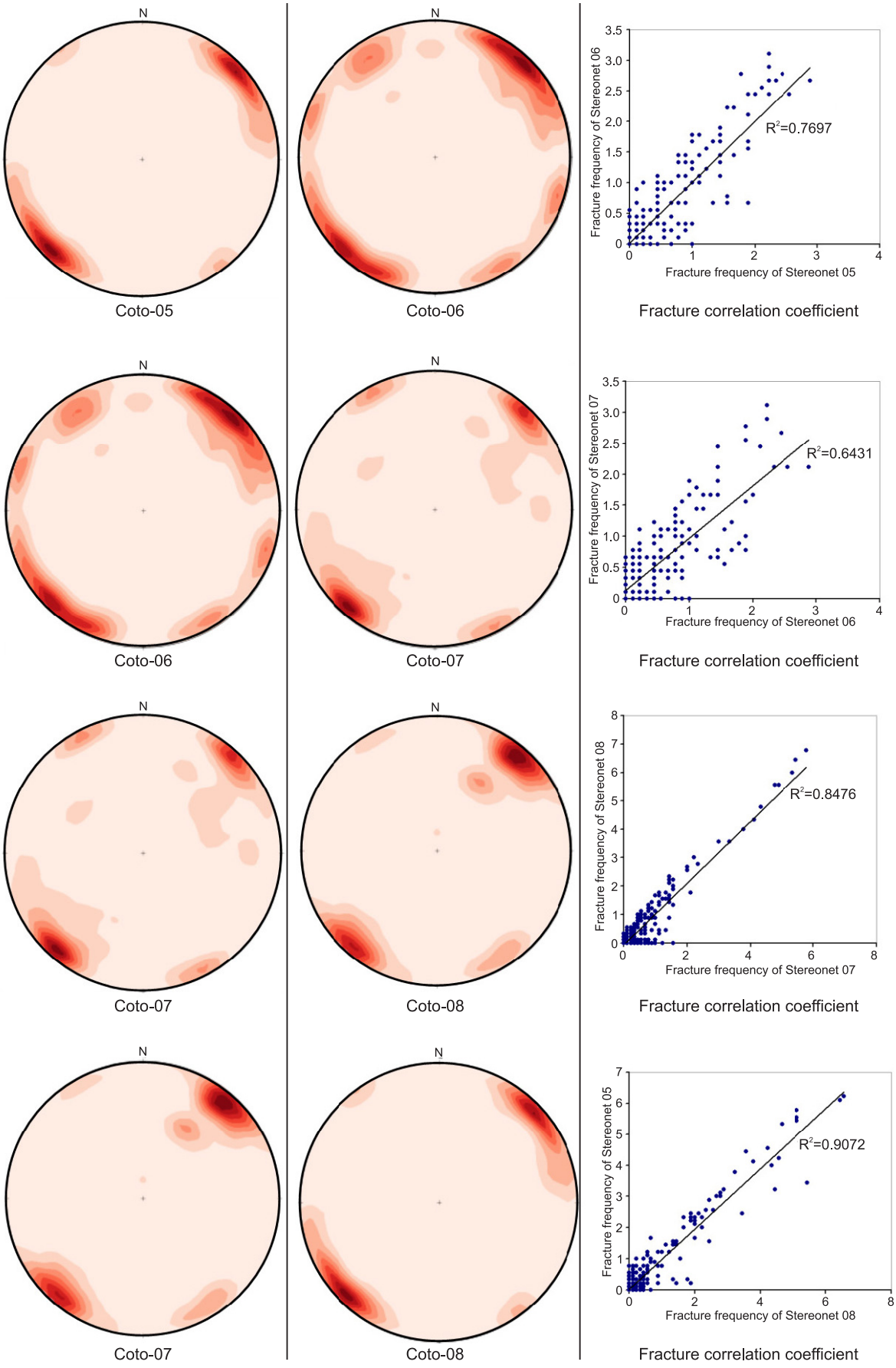

Fig. 3 (continued).

Рис. 3 (продолжение).

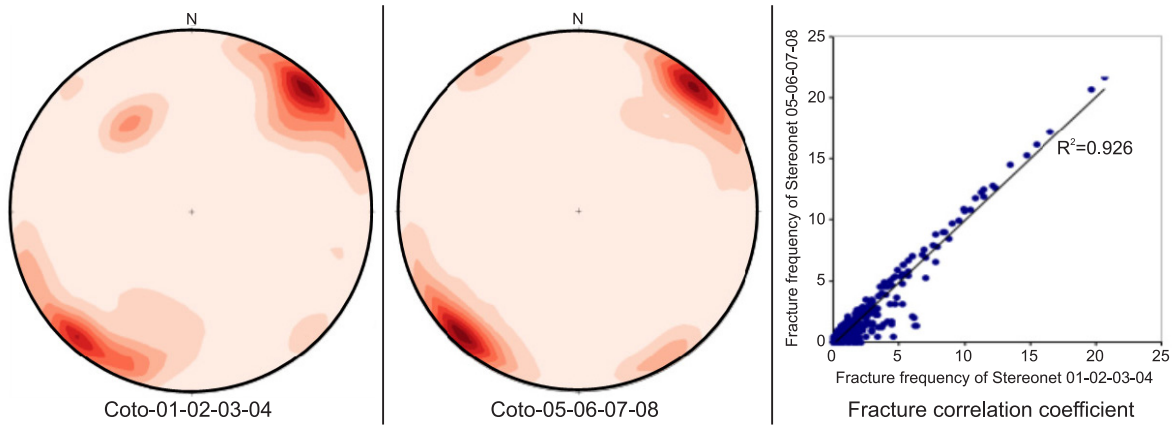

Fig. 3 (end).

Рис. 3 (окончание).

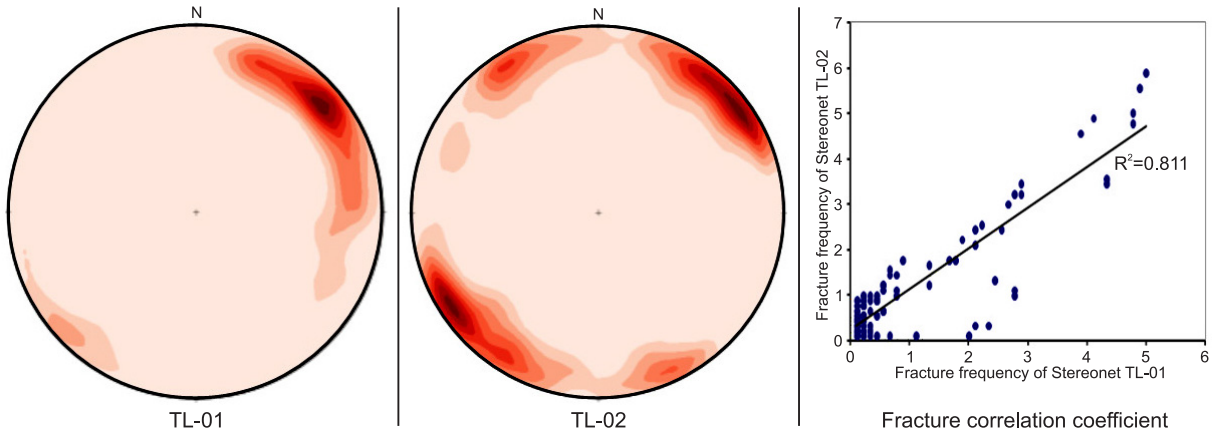

Fig. 4. Lower hemisphere projection of fracture poles and the correlation coefficient for the Thanh Lan Island.

Рис. 4. Нижняя полусфера проекции полюсов трещин и их коэффициент корреляции на острове Тань-Лан

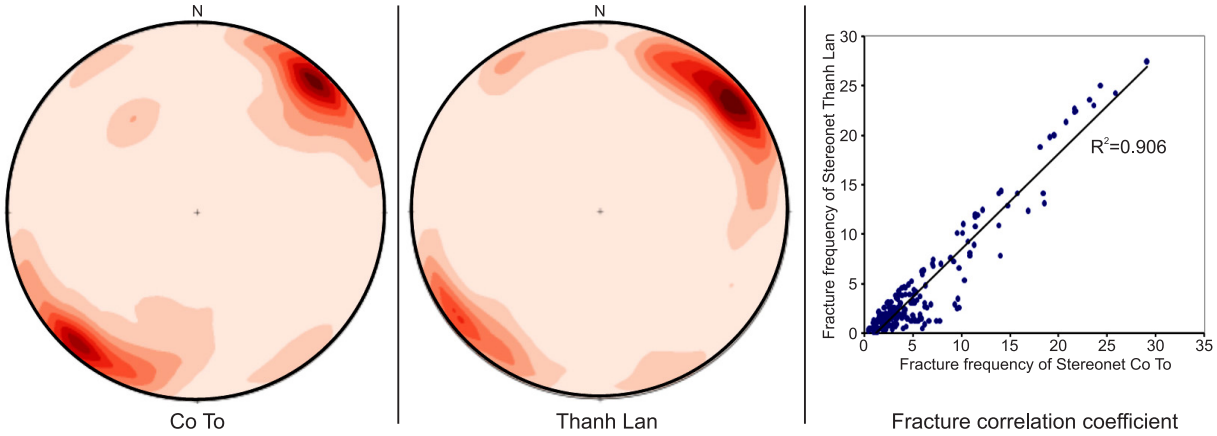

Fig. 5: Lower hemisphere projection of fracture poles and the correlation coefficient for the Co To and Thanh Lan islands.

Рис. 5. Нижняя полусфера проекции полюсов трещин и их коэффициент корреляции на островах Ко-То и Тань-Лан.

T a b l e 2. **Fracture correlation coefficients for the Co To island, Thanh Lan island, and two these islands**

T а б л и ц а 2. **Коэффициент корреляции трещиноватости на островах Ко-То и Тань-Лан и на обоих островах**

No	First Window	Second Window	Fracture correlation coefficient
01	Coto-01	Coto-02	0.785
02	Coto-02	Coto-03	0.881
03	Coto-03	Coto-04	0.854
04	Coto-04	Coto-01	0.800
05	Coto-05	Coto-06	0.769
06	Coto-06	Coto-07	0.643
07	Coto-07	Coto-08	0.847
08	Coto-08	Coto-05	0.907
09	Coto-01-02-03-04	Coto-05-06-07-08	0.926
10	TL-01	TL-02	0.811
11	Coto	Thanh Lan	0.945

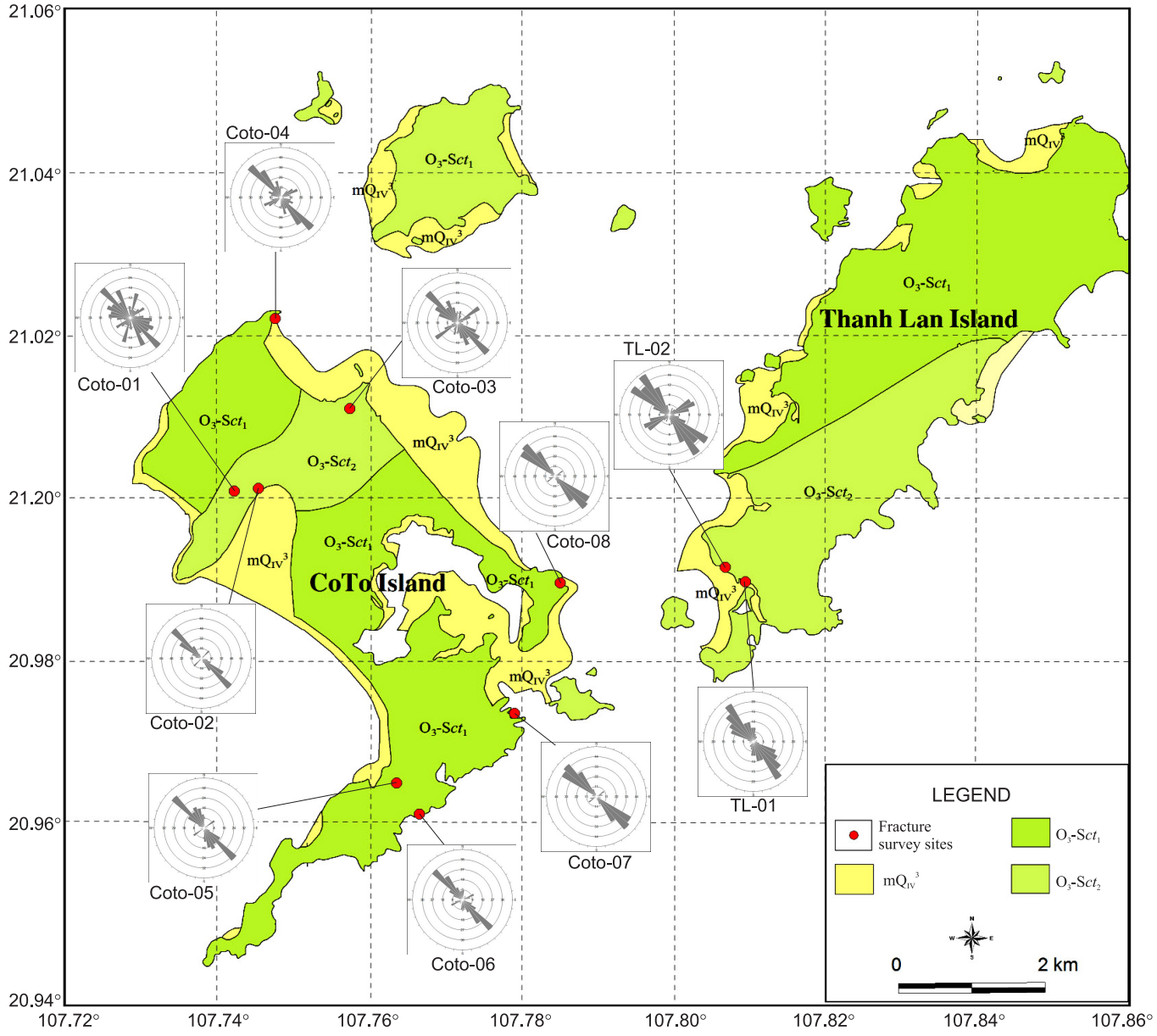

Fig. 6. Map of the Co To – Thanh Lan islands, showing the rose graphs of fracture orientation [*Truong Thanh Phi, 2015*].

Рис. 6. Карта островов Ко-То и Тань-Лан и роза-диаграммы ориентации трещин [*Truong Thanh Phi, 2015*].

Fig. 7. Incline of sedimentary layers in the northeastern area on the Co To Island.

Рис. 7. Наклон осадочных слоев в восточной части острова Ко-То.

5. Conclusion

According to our analysis of the quantitative correlation of fracture distribution for ten survey sites on the Co To-Thanh Lan islands in Quang Ninh province, Viet Nam, the fracture correlation coefficient is mostly over 0.80. The high correlation values estimated for the survey sites clearly reflect the geodynamical setting of the study area.

On the Co To-Thanh Lan islands, 1634 fracture measurements were taken at 10 different survey sites, and using the correlation method, the fracture correla-

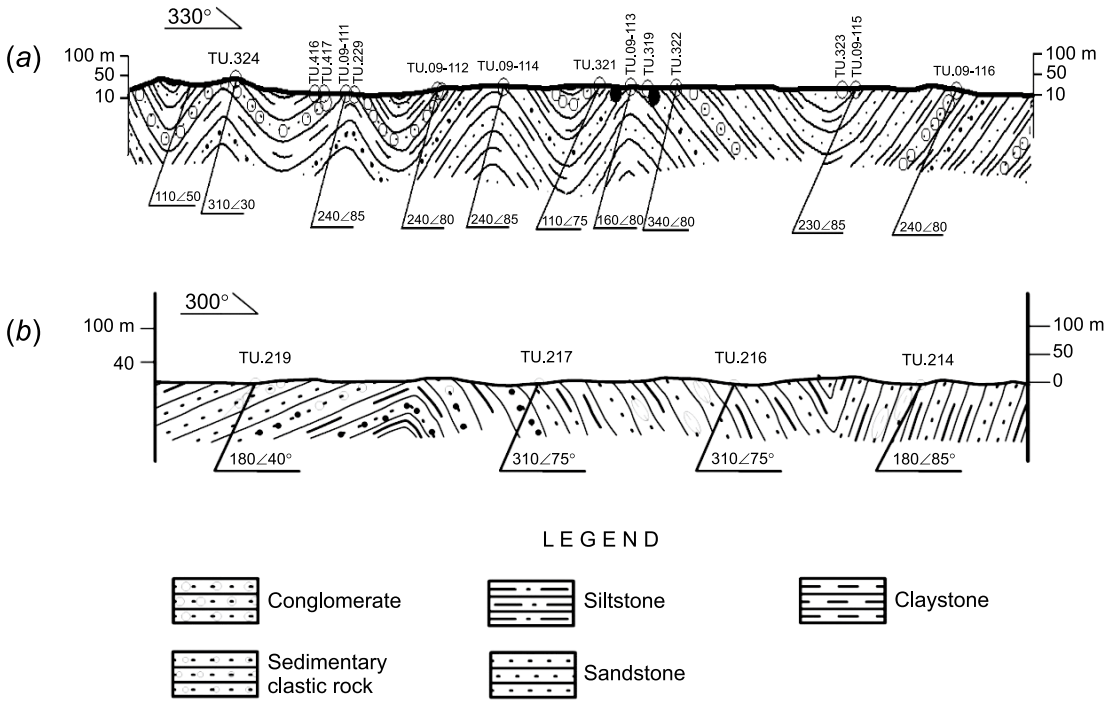

Fig. 8. Geological cross sections: (*a*) East of the Thanh Lan Island; (*b*) Northeast of the Co To Island [*My Cung Dang, 2013*].

Рис. 8. Геологические разрезы: (*a*) на восток от острова Тань-Лан; (*b*) на северо-восток от острова Ко-то [*My Cung Dang, 2013*].

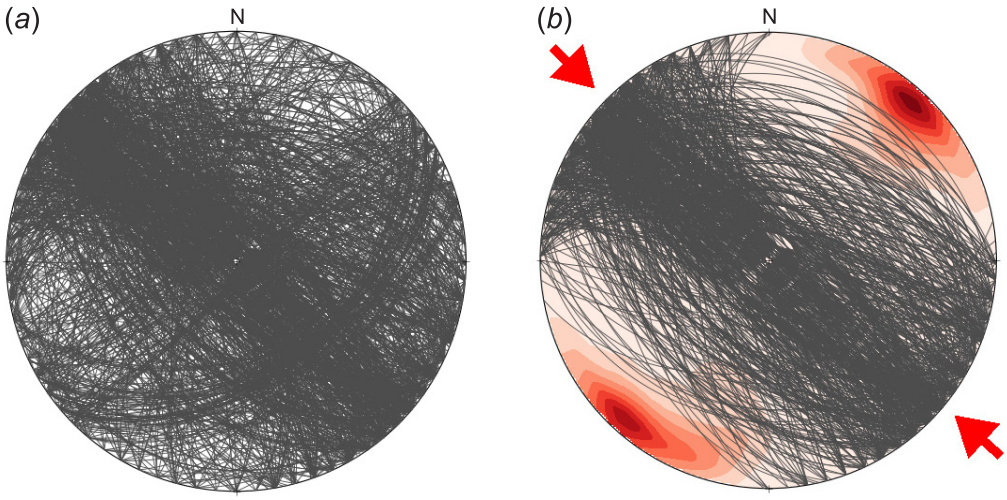

Fig. 9. Great circle of total fracture orientations for eight survey sites on the Co To island (*a*) and great circle of fracture orientations in NW-SE (042/81 and 224/79) (*b*).

Рис. 9. Круговая диаграмма общего количества ориентаций трещин для восьми изученных участков на острове Ко-То (*a*) и круговая диаграмма ориентации трещин на СЗ-ЮВ (042/81 и 224/79) (*b*).

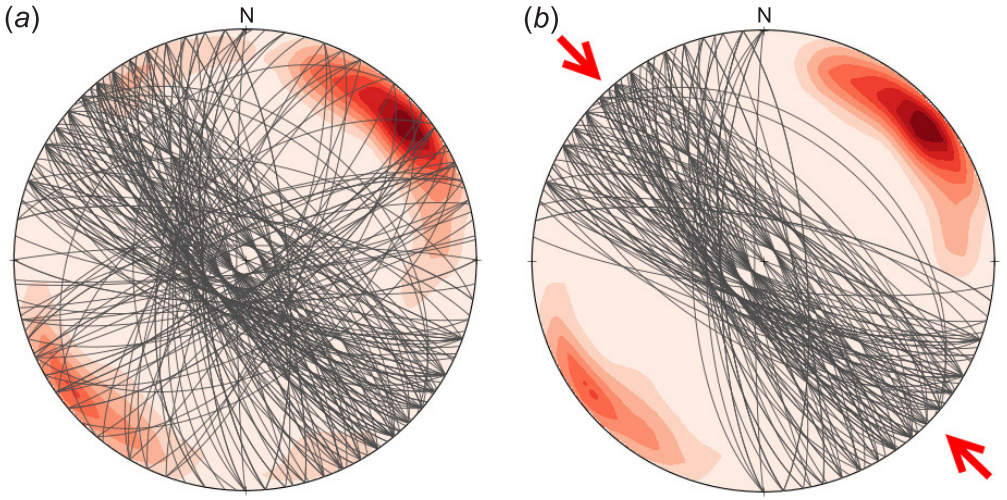

Fig. 10. Great circle of total fracture orientations for two survey sites on the Thanh Lan island (*a*) and great circle of fracture orientation in NW-SE (053/81 and 229/79) (*b*).

Рис. 10. Круговая диаграмма общего количества ориентаций трещин для двух изученных участков на острове Тань-Лан (*a*) и круговая диаграмма ориентации трещин на СЗ-ЮВ (053/81 и 229/79) (*b*).

tion coefficients among 11 pairs of stereonet windows were calculated. The calculated fracture correlation coefficients range as follows: over 0.90 (27.27 %); over 0.80 (45.45 %); over 0.70 (18.18 %); and over 0.60 (9.09 %).

The experimental results obtained in this study have important significance for the division of the structural domain and determination of the stress state of rock deformation phases, as well as for confirmation of the significance of the correlation method in analyzing the structural geology and geotechnical engineering.

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