# CORRELATION BETWEEN FAULTS ORIENTATIONS AND HYDROCARBON RESERVOIRS IN THE EAST SEA

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**Summary**

***The East Sea is a large area complicated by a variety of fault systems. There are many differences in the depth, orientation and dip angle of the faults. In the Cenozoic sedimentary basins, most of the faults are determined by using seismic data. Otherwise, wherever seismic data is sparse or in the Pre-Cenozoic basement, the faults are frequently determined by interpreting gravity data.***

***In this paper, a method of orientation analysis of faults systems to define the major trends of geological structures as well as estimate the correlation between fault orientations and hydrocarbon reservoirs in the East Sea has been carried out. The method has indicated the reliability of using faults systems for discovering and delineating areas with hydrocarbon potential. It can be said that, for particular areas, the existence of the hydrocarbon reservoirs is always consistent with the respective orientation of fault systems. As a result, the close correlation between fault orientations and hydrocarbon reservoirs is demonstrated. The method should be applied as an effective tool for hydrocarbon exploration in the East Sea.***

## 1. Introduction

The essential significance of orientation analysis of fault systems for oil and gas exploration has been proved by many studies that have been carried out in the East Sea as well as all over the world. The study and determination of fault systems in the East Sea has been done over a period of many years with differences in grade and details determined. Especially, the fault systems in the Cenozoic basins have been meticulously studied by oil and gas exploration companies from inside and outside Vietnam. However, as yet, these studies apply only to faults within sedimentary basins, not to faults in the Pre-Cenozoic basement. In this paper, for analysis of fault orientations, all the fault data and information on oil and gas field distributions that are available in the study area have been collected. Most of these are the results of studies conducted by the Institute of Marine Geology and Geophysics and the Vietnam Petroleum Institute. Concurrently, the gravity data has also been interpreted to determine the faults that are present in the Pre-Cenozoic basement as well as in areas that have no fault data as yet.

In this paper, some sample areas have been selected to apply the method of orientation analysis of faults. In these sample areas the fault information are abundant and they are considered as the high oil and gas potential areas. The sample areas were selected from a large region, covering the whole continental shelf and they are representative of the different geological structures in the East Sea. The correlation between fault and oil and gas reservoirs is defined by analysing these fault orientations. The information on known oil and gas fields is compared with the study results in order to affirm the reliability of the method.

The results presented in this paper prove the significance and reliability of using orientation analysis of faults in oil and gas exploration, especially for offshore areas.

## 2. Orientation analysis of faults for oil and gas exploration

### *2.1. Database creation*

*2.1.1. Information on oil and gas fields in the study area*

Collection and integration of information on known oil and gas fields are important for hydrocarbon exploration in other new areas. We can consider this as datum information that can be usefully applied for other geophysical methods. The spatial distributions of known oil and gas fields are consistent with geological structure

and fault orientations. In this paper, the results from the orientation analysis of faults can be compared with the information on known oil and gas fields. As a result, one can produce comments and detailed plans for oil and gas exploration in different areas and at different levels. Most of the oil and gas field data were collected and integrated from project KC-09-02 (National Marine Research Project KC-09) [2, 6], which was carried out by the Institute of Marine Geology and Geophysics and the Vietnam Petroleum Institute during different periods (Fig.1).

*2.1.2. Collection of fault information*

Studies of faults in the East Sea have been carried out over the past many years. However, the studies with wide scope and of high quality only started in the 1980's. The results achieved have allowed the construction of maps of fault characteristics and distribution. More and more, fault characteristics are being upgraded and detailed by many marine research projects. Nevertheless, because of the diversity and dispersion of these data from surveys and research projects, the maps of fault characteristics and distribution were constructed with differences in geographic projection and resolution as well as accuracy. In project KC-09-02 (2001 - 2005) [2], many maps, such as gravity, tectonics and deep structure, were constructed and these maps integrate all the newest information on fault characteristics in the East Sea.

In addition, many fault investigations have been undertaken by oil and gas companies and these investigations have accurately revealed the characteristics and distribution of fault systems. Most of the fault data are concentrated in the continental shelf, especially in the sedimentary basins such as Song Hong, Phu Khanh, Cuu Long, Nam Con Son and Ma Lai - Tho Chu basins, where oil and gas exploration is most intense [6]. However, for deep basins and remote areas, the fault data are very sparse and inhomogeneous.

*2.1.3. Determination of fault systems from gravity data*

Though fault data in the East Sea are very abundant, most data are concentrated in the continental shelf and sedimentary basins. Therefore, in this study, the collection of the known fault data and the determination of unknown faults by interpreting gravity data were carried out simultaneously. Methods of analytical upward-downward continuation and horizontal gravity gradient and maximal gravity gradient were applied to determine 3D fault geometry. The processes of gravity data interpretation were divided into two steps: first step, calculation of horizontal gravity gradient at different high levels; second step, the maximal values of horizontal gravity gradient were calculated from the horizontal gravity gradient in the first step for locating the edges of geological bodies

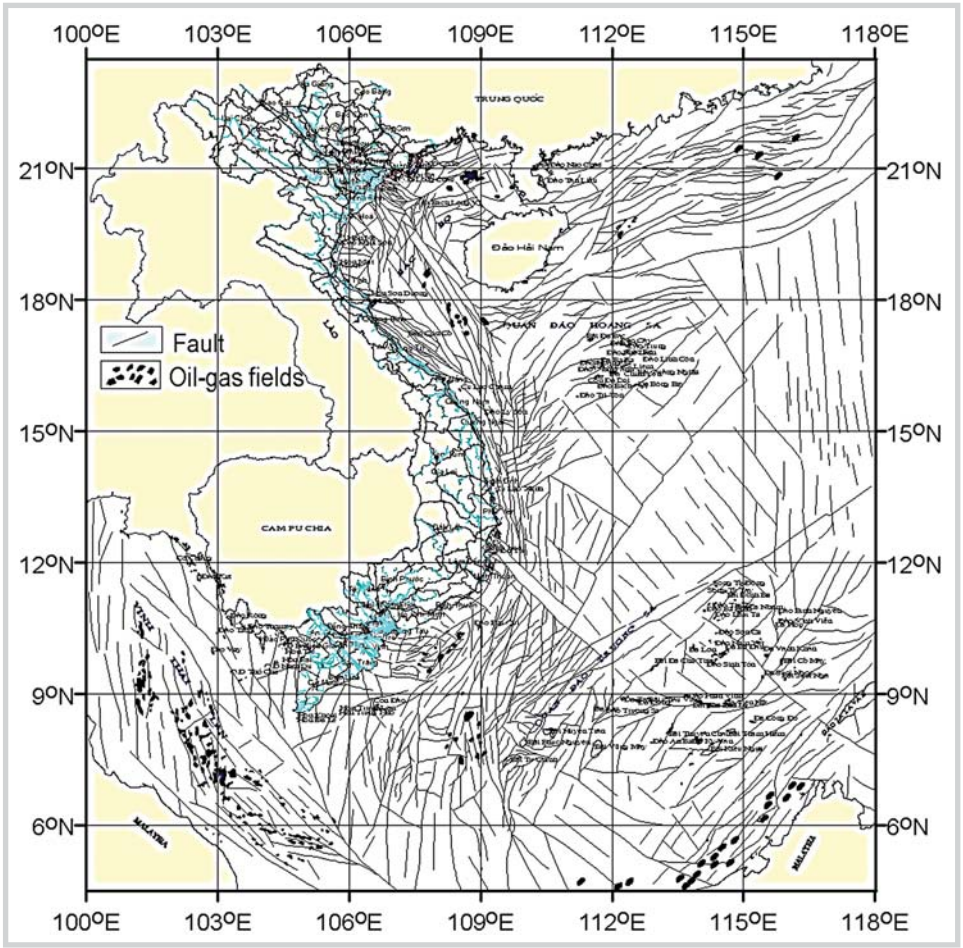


***Fig.1.*** *Distribution of fault systems and oil-gas fields in the East Vietnam Sea (after the marine research projects at Institute of Marine Geology and Geophysics)*

(such as faults) [1, 3, 5, 6, 7]. The map of gravity-fault distribution was constructed by integrating and linking locations of the maximal gravity gradient values.

Integrating and combining the results at items 2.1.1, 2.1.2 and 2.1.3, the map of distribution of fault systems and known oil and gas fields in the East Sea was compiled (Fig.1).

*2.1.4. Fault information correction*

The fault information was gathered from different sources; therefore errors such as their coordination, spatial distribution and existence are inevitable. The faults within the sedimentary basins are determined by seismic and gravity data, the faults in the Pre-Cenozoic basement and in areas with no fault data are only defined by using gravity data. For the purpose of this paper, the authors have compared and corrected the faults collected with those calculated in order to compile a unified map of fault distribution with a standard geographic projection (Fig.1).

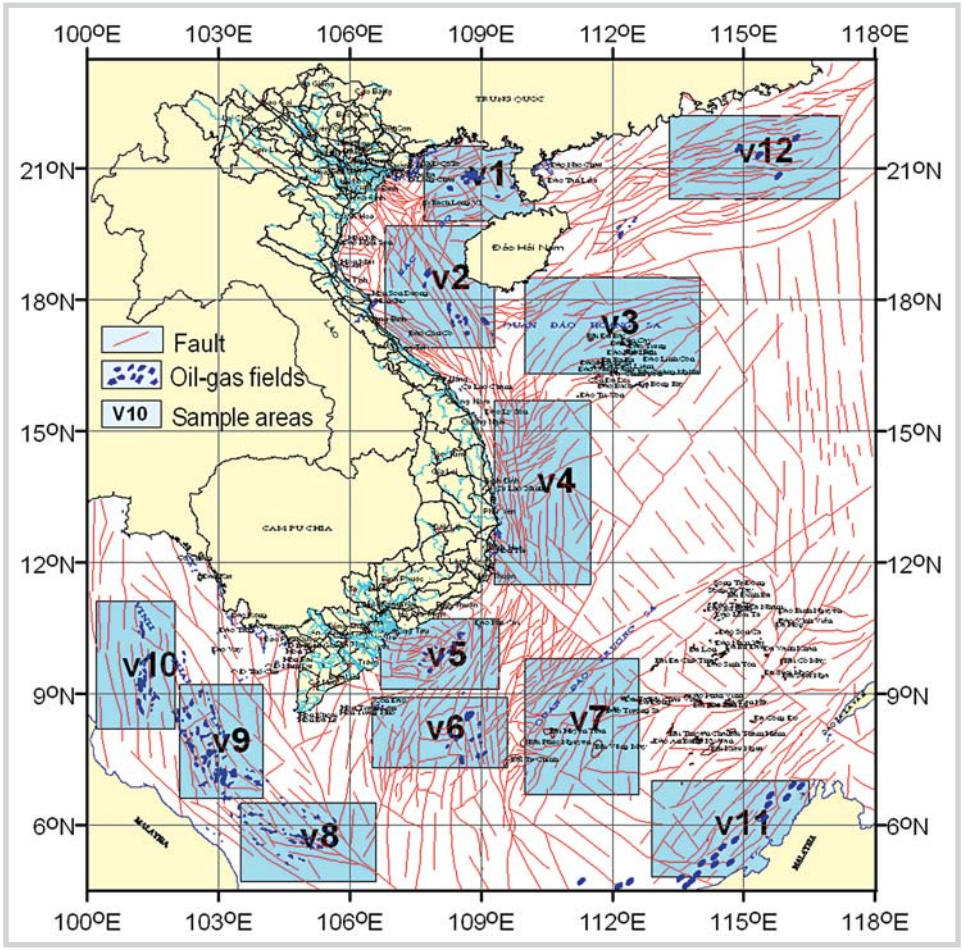


***Fig.2.*** *Distribution of sample areas using for orientation analysis of faults*

*2.1.5. Calculation of fault orientations*

Orientation is one of the characteristics of linear features such as fault and shear zones. All the fault data were digitised and transformed to a unique geographic projection - Mercator WGS84. Calculation and representation of fault orientation are the major task in this paper. The software GeoMapVector, Ras2vec and MapInfo, Ilwis GIS packages were used in combination to do the task. In this study, the faults in the area are divided into 12 sample-areas, assigned from V1-V12. They are used to calculate the orientation of faults (Fig.2).

The GeoMapVector program for MapInfo was used to calculate the azimuth (trend, orientation) of faults in a MapInfo table. The azimuth direction chosen can be either from the first node in the fault-line towards the last node, or vice versa. For tables in an Earth projection the geodetic azimuth calculated is based on the WGS84 ellipsoid with azimuths given as the 360° angle clockwise from longitudinal North.

The calculating procedure works on the current selection of the faults and produces a new table with the orientation values of the faults. The orientation values of the faults are generated based on their length instead of usual frequency [4]. The program is useful for capturing the orientation of digitised line data such as faults and fractures and for analysis of these data.

*2.1.6. Representation of fault orientation*

Orientation is one of the most revealing characteristics of linear features, such as surface faults and basement faults. A rose diagram is the most effective way to represent the information on orientations of linear features [4]. The fault's orientations calculated in item 2.2.2 above were used for drawing the rose diagrams. Here, a fault's azimuth

angle is chosen from 0 - 360° clockwise Northwards. Rose diagrams for all the faults acquired in the East Sea were generated by using Ilwis 3.0 GIS package (Figs.3 - 8).

Fig.3 shows the rose diagrams of orientations of faults systems in the North Bac Bo and Song Hong basins. It can be seen from the diagrams that the faults in these areas have two orientations: Southwest - Northeast and Southeast - Northwest. However, the main orientation of the faults is Southwest - Northeast, this reflects the major geological structure of the sedimentary basins. The faults with Southeast - Northwest direction are minor, which reflect the local geological structures that develop inside the sedimentary basins.

Fig.4 shows the rose diagrams of orientations of fault systems in the Southeast Hainan and Phu Khanh basins. The orientation of the faults in the Southeast Hainan basin is Southwest - Northeast and that in Phu Khanh basin is longitudinal. Besides, in the Phu Khanh basin there are two more, less frequent orientations of faults; these being Southwest - Northeast and Southeast - Northwest. This may be related with faults inside the sedimentary basin.

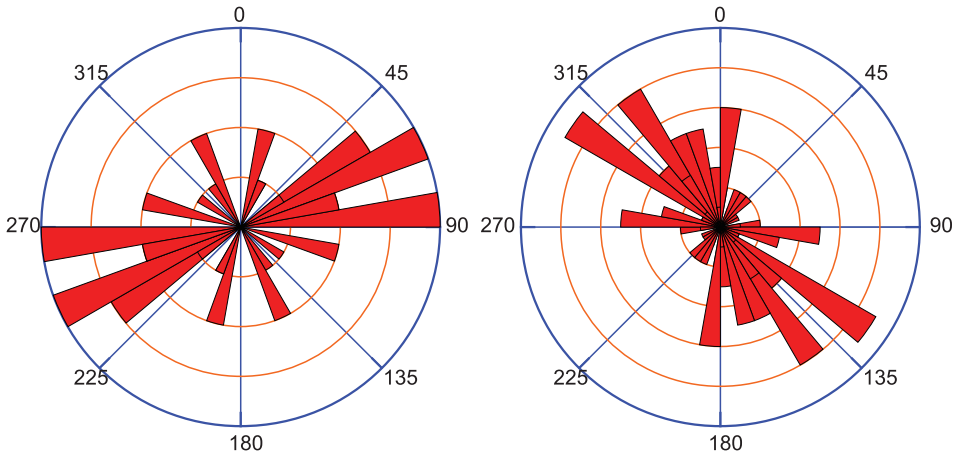


***Fig.3.*** *Rose diagrams representing orientations of faults in North Bac Bo and Song Hong basins (at sample V1 and V2)*

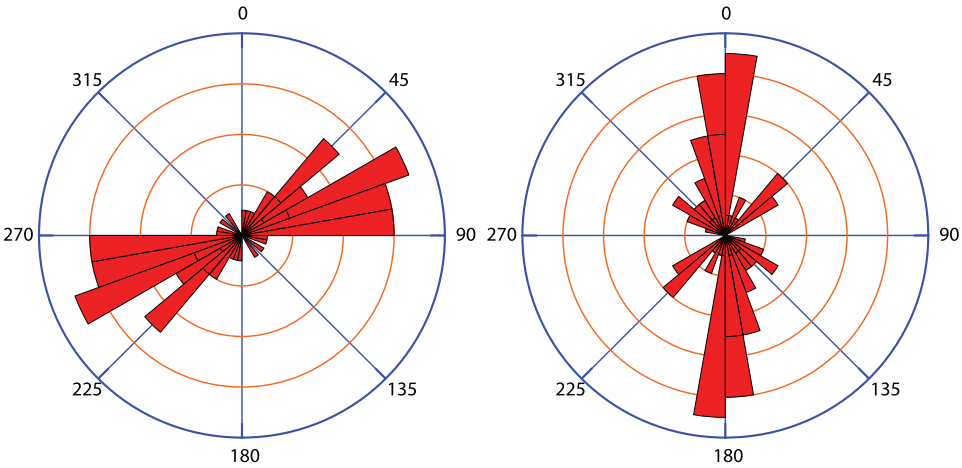


***Fig.4.*** *Rose diagrams representing orientations of faults in Southeast Hainan and Phu Khanh basins (at sample V3 and V4)*

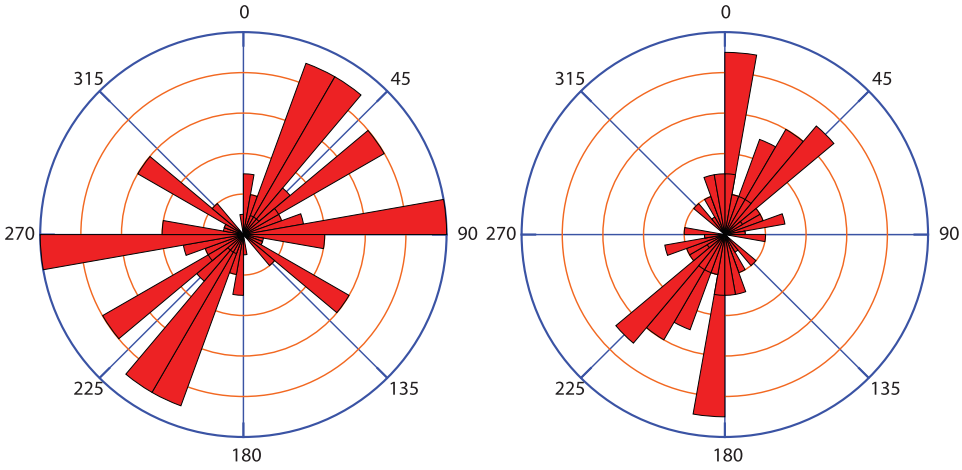


***Fig.5.*** *Rose diagrams representing orientations of faults in Cuu Long and Nam Con Son basins (at sample V5 and V6)*

The orientations of the faults in Cuu Long and Nam Con Son basins are represented in Fig.5. There are three orientations of faults in these areas, these are Southwest - Northeast, Southeast - Northwest and West - East, however, the major orientation is Southwest - Northeast. The Southwest - Northeast and longitudinal trend are two primarily orientations of the faults in the Nam Con Son basin.

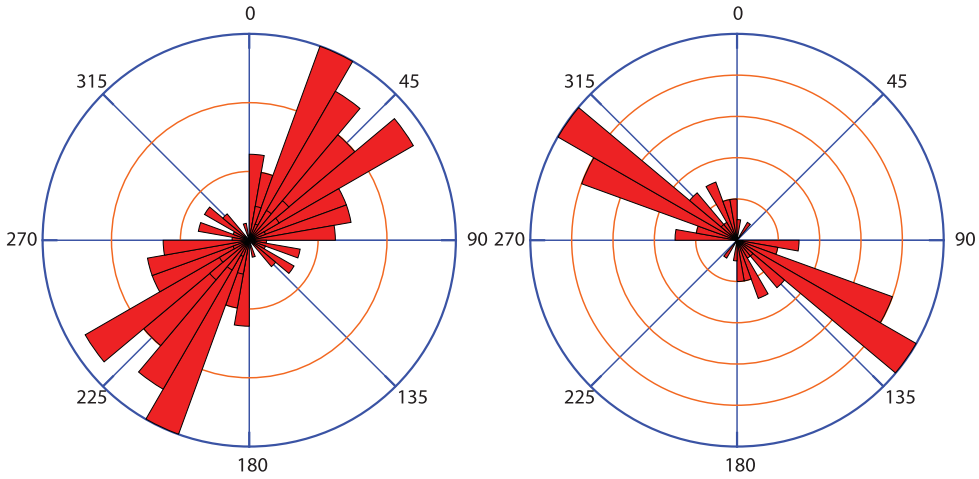


***Fig.6.*** *Rose diagrams representing orientations of faults in Tu Chinh - Vung May and Ma Lai - Tho Chu basins (at sample V7 and V8)*

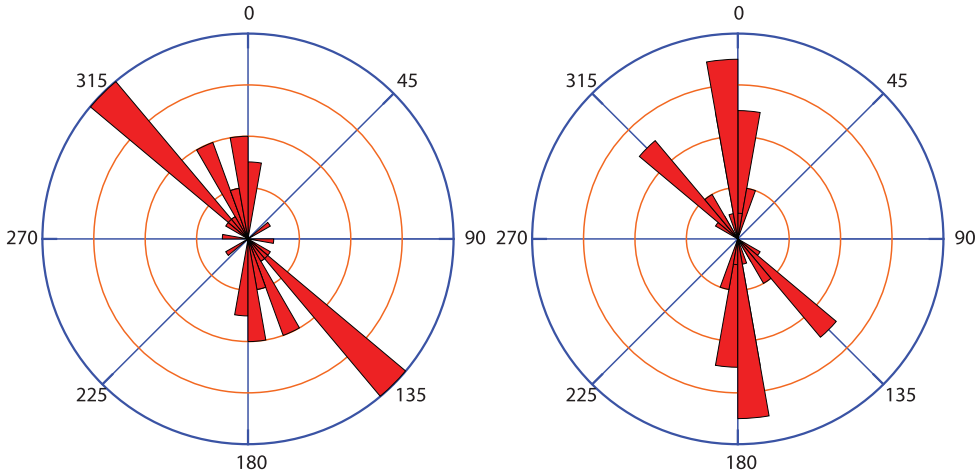


***Fig.7.*** *Rose diagrams representing orientations of faults in Ma Lai - Tho Chu and Pattani basins (at sample V9 and V10)*

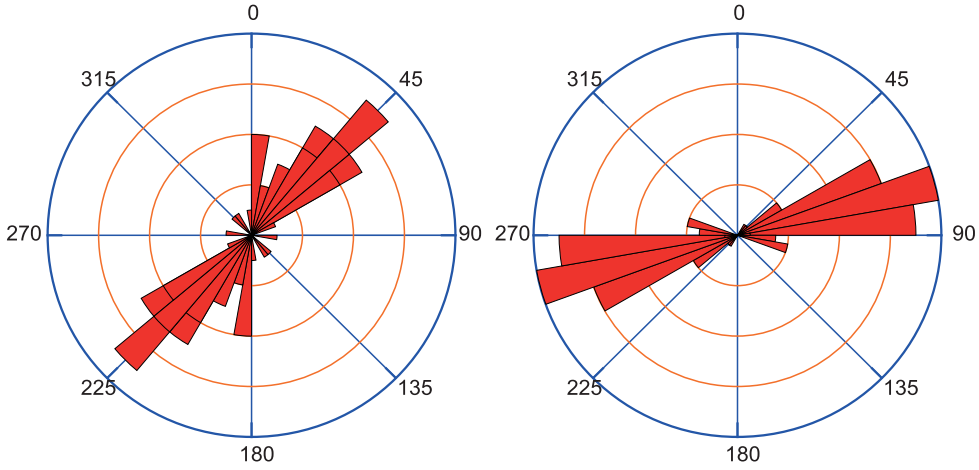


***Fig.8.*** *Rose diagrams representing orientation of fault in Borneo and Chau Giang basins (at sample V11 and V12)*

In the Tu Chinh - Vung May basin, the primary orientation of faults is Southwest - Northeast. The Southeast - Northwest direction is minor and quite subdued in the rose diagram (Fig.6). In the Southeast of the Ma Lai - Tho Chu basin (V8) area, the faults develop Northwest - Southeastwardly.

In the Northwest part of the Ma Lai - Tho Chu basin the orientations of faults are Southeast - Northwest and sub-longitudinal. In this area, the faults in sub-longitudinal direction are quite dense. In Pattani basin, the main orientation of the faults is longitudinal and the minor orientation is Northwest - Southeast (Fig.7).

In this paper, the fault's orientation in two adjacent areas of the East Sea, the Borneo and Chau Giang basins (V11 and V12 areas) are also analysed. In the depressed Borneo basin, the primary orientation of faults is Northwest - Southeast and consistent with the geological structure in the area. In the Chau Giang basin, the fault orientation is also Northwest - Southeast but it inclines towards a sub-latitudinal direction (Fig.8).

### 3. Assessment of results

Based on the results from orientation analysis of faults and known oil and gas fields' information, it is reasonable to conclude that distribution of known oil and gas fields is quite consistent with orientation of the fault systems in the East Sea. The correlation between fault orientation and oil and gas distribution in the study area can be generally described as follows:

In the V1 and V12 areas, the distribution of the oil and gas fields is latitudinal. These are consistent with the orientation of the fault systems in the areas (Figs.1, 3 and 8).

In the V2 area, the Song Hong sedimentary basin, the fault orientation is Southeast - Northwest. The correlation between fault orientation and oil and gas fields' distribution can be seen clearly in Figs.1 and 3.

The V5 and V6 areas cover the Cuu Long and Nam Con Son sedimentary basins. Here, fault orientations are different but also consistent with the distribution of oil and gas fields (Figs.1 and 5).

Distribution of oil and gas fields in the V8, V9 and V10 areas are different in trends. These depend concretely on the geological structure in particular basins, but generally the distribution is quite consistent with fault orientation in the areas (Figs.1, 6 and 7).

Finally, in the V11- Borneo basin, the distribution of the oil and gas fields is Southeast - Northwestward. In this area, the faults are developed in only one orientation that is consistent with distribution of the known oil and gas fields (Figs.1 and 8).

**4. Remarks and conclusion**

Based on the results as summarised above, an assessment of the significance and reliability of fault orientation analysis for hydrocarbon exploration in the East Sea leads to some remarks and conclusions as follows:

The analysis in this study requires a tremendous amount of information concerning faults, the distribution of the known oil and gas fields and gravity data. Some of above-mentioned information is derived from interpretation of seismic and gravity data which must be digitised and created in standard format and represented in geographic projection.

The consistency in orientation between faults and the known oil and gas fields shows a close correlation between fault characteristics and the existence of oil and gas reservoirs. It is practical to conclude that any potential new oil and gas reservoirs, if they exist, will likely be associated with the fault's orientation.

From the achieved results, it can be concluded that the orientation analysis of faults should be applied as an effective tool for oil and gas exploration. It could be used for preliminary delineation of locations for more detailed geological and geophysical surveys in the East Sea.

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