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Fault orientation modeling of Sonda- Jherruck coalfield, Pakistan

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Fault Orientation

Dip

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Abstract

Faults are the most critical tectonic factors in geological structures, which have major economic impacts on mining economics. Thus it is necessary to understand faults in order to identify the actual risks and complications associated with mining. In the preliminary investigation of the Sonda-Jherruck coalfield, 3D geological modeling was not performed. The purpose of this work was to perform fault orientation modeling in order to document pre-mine planning information and discuss the obstacles that may cause problems in mine planning and development stages. Using the drill hole data, 3D fault models based on the calculation of dip angle and dip direction were established. In the first step, surface models of coal seams were established by applying the triangulation method to the coal seam roof elevations. Then an appropriately oriented grid was overlain to regularize the data and to find the unknown points. The calculation of dip and dip direction was done using an algorithm. The models showing the variation in the dip and dip direction were generated using the inverse distance squared weighted (ID^{2}W) interpolation technique. The generated 3D models were compared with the pre-existing fault lines (based on the aerial map). An attempt was made to create comprehensive models that demonstrate a better understanding of the faults in the studied area.

1. Introduction

Improving mining operations through advanced computer-aided solutions has attracted great attention in the current field of geoscience research works. The risks associated with geological uncertainties have adverse impacts on the exploration and exploitation of underground coal resources. Due to the economic impact of geological structures, 3D modeling has a far-reaching influence on mine planning and design. Reliable resource analysis is essential to determine the most profitable mining method that can influence the project-related value and economic risk. The proper design and structure of mines are the key issues in Pakistan [1, 2]. In order to improve the efficiency of Pakistan's mining sector, it is necessary to use the mine planning software to assess the resources and improve decision-making strategies. 3D geological modeling is an effective way to create reliable 3D models to better understand ore geometry. In order to avoid inaccuracy in reserve estimation and resource planning, a detailed understanding of the fault zones is essential. Geological uncertainties may lead to significant delays in production, reduction of the expected level of mining, a danger to the safety, and a heavy impact on the financial viability of mines [3]. In addition, disturbances due to faults located in mining areas have also been widely observed and recorded [4]. Faults in the thin coal seam area have substantial economic impacts on mining. Experience has shown that the drill hole based investigations do not provide sufficient coal seam models to address planning risks associated with these hazards. Therefore, unplanned costs may reduce productivity, and high strata control may

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affect operational performance under problematic geologic conditions [5]. Thus reliable interpretation and estimation of geological structures are required. Many techniques are available for fault modeling based on different data types. Gribble formed a fault model by overlying an appropriately oriented grid, and the data was regularized on the digital terrain model of the geologic surface [6]. The dip between data points was calculated and the dip change model was created. Wua et al. simulated a geological structure with insufficient data by a stepwise refinement on multiple data to improve the accuracy of 3D models [7]. Based on the typical sparse data, Caumon et al. built an efficient structural fault model and provided additional key concepts, principles, and procedures for geological modeling tasks with special emphasis on quality control [8]. Tercan et al. defined geological discontinuities by modeling fault blocks based on the wrinkling and un-wrinkling methods [9]. Using the drill hole data, Ünal et al. generated block models for fault detection by estimating the dip and dip direction [10]. Unver constructed a 3D solid model for fault detection by combining the top-bottom and section methods [11]. Lee et al. built a fault network model from contact curves and dip vectors derived from the surface geological map, cross-sections, faults, and digital elevation models [12]. Since only drill hole data is available for the Sonda-Jherruck coalfield, it is important to effectively use the available data for resource evaluation so as to avoid the inaccuracies in the understanding of the fault zones. According to a literature review, a few studies have focused on the computer-aided resource assessment of coal deposits in Pakistan so far. Therefore, there is an urgent need to adopt the most effective resource assessment method to obtain appropriate mine planning. However, due to the unavailability of detailed geological information, it is difficult to obtain appropriate mine plans. This paper presents an improved fault orientation modeling technique carried out by effectively utilizing the existing drilling data. The method has effectively highlighted the faults in the coalfield. The established models can be used to identify the potential problems related to further exploration targets and mine plans, which may have a significant impact on the financial viability of mines. This paper has been organized as follows. The first section deals with the literature review. The second section describes the studied area in terms of the geological setting. The third section explains the procedure of fault modeling. The final section includes a conclusion.

2. Field Description

Sonda-Jherruck, located in the Sindh Province, is the second largest coalfield in Pakistan. Due to insufficient investment, this coalfield has not yet been developed. The geographical position of the studied area showing the coalfield boundary and the location of drill holes is shown in Figure 1. The basic exploration work commenced in the late 1980s and early 1990s by the Geological Survey of Pakistan (GSP) and the United States Geological Survey (USGS) to assess the coalfield [13-20]. However, an advanced exploration and resource assessment have not been carried out up to date. The geological age of the Sonda-Jherruck coalfield has emerged since the Cenozoic until Eocene stratigraphic units. The coal is formed in two formations, Laki and Bara, with seven different coal beds [20, 21]. The lithology and position of coal seams in the studied area are represented in the generalized stratigraphic column (Figure 2). According to GSP, the coal quality has been reported as Lignite A to sub-bituminous C [20, 22]. The total coal resources have been estimated to be 4.66 billion tons, whereas the exploitable resources have been estimated to be 1.59 billion tons [23]. There are no other complications in mining except the overburden. The area tends to the West, and has hydrological links with water permeable areas along the Indus River. Only half of the southern part of the region has been mapped at a scale of 1:250000. Figure 3 shows the geological map of the studied area showing the fault lines identified by USGS [20]. The accuracy and uncertainty of previous interpretations cannot be predicted and assessed without a priori model.

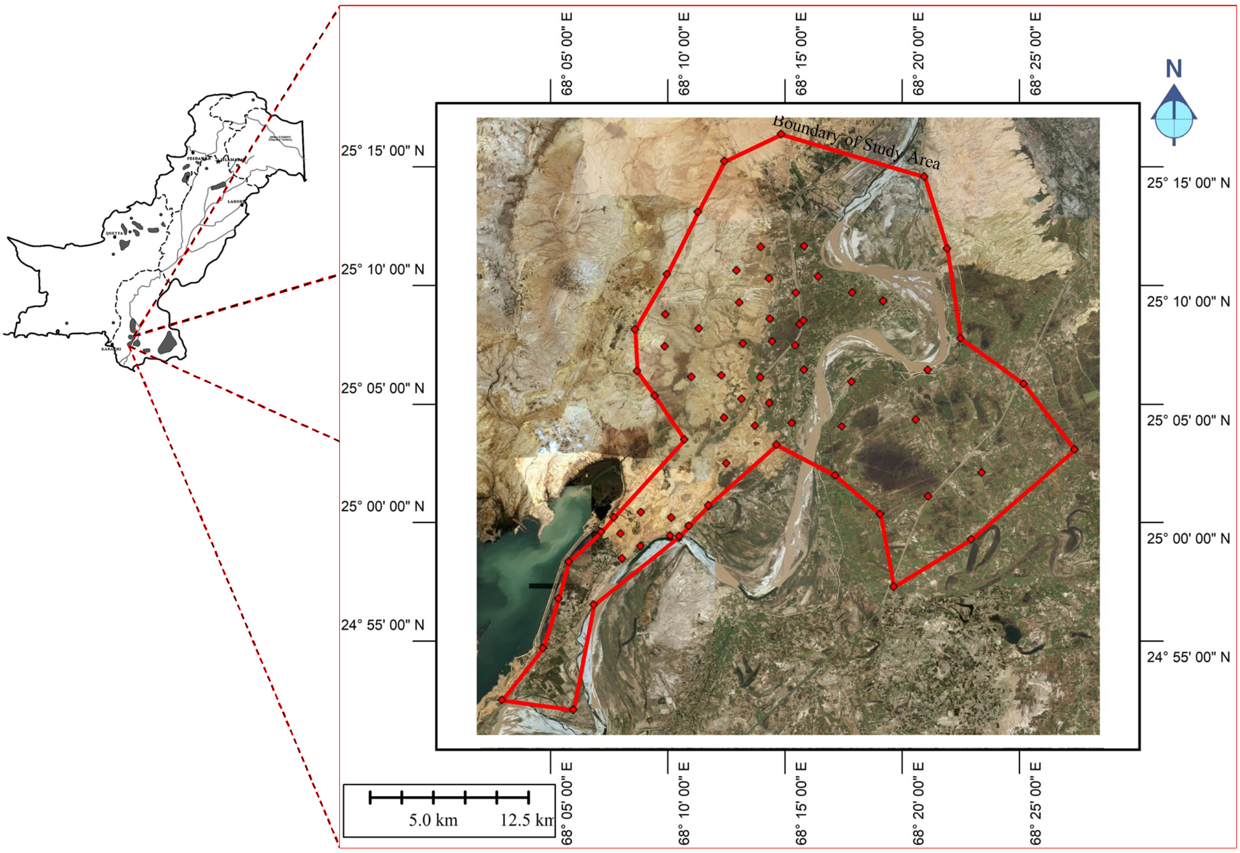

Figure 1. The geographical position of the study area.

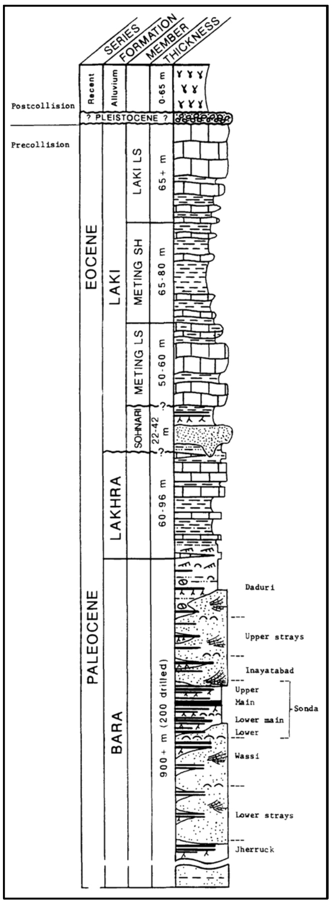

Figure 2. Stratigraphy column of the study area [20].

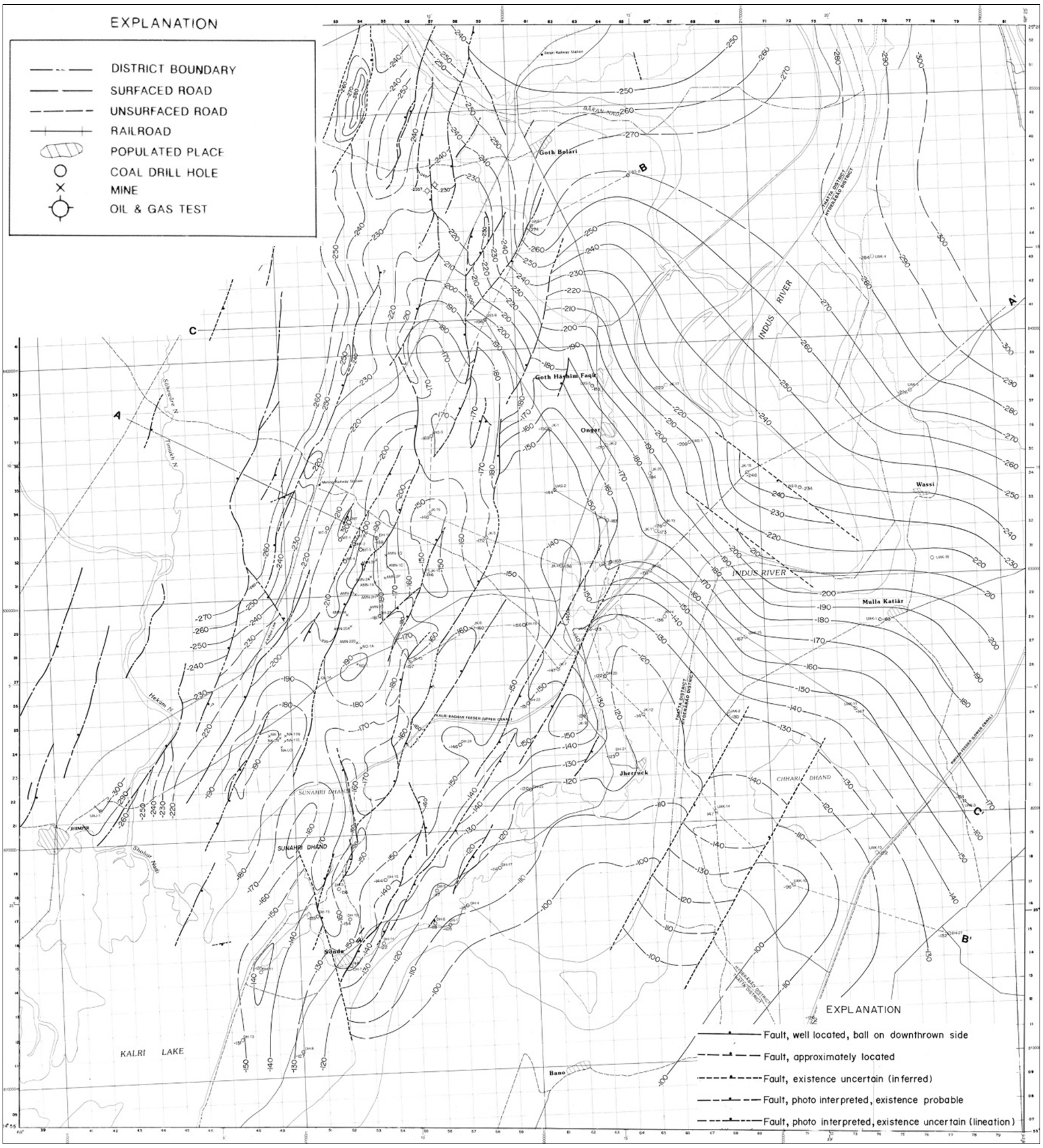

Figure 3. Fault map of the study area showing USGS faults lines.

3. Fault Modeling

In order to know the practical complications in the mining engineering operations, it is necessary to have a comprehensive understanding of the fault zone. In this work, fault interpretation modeling was used to obtain reliable interpretation results from the drill hole data. The data was based on the information obtained from exploratory drilling, including location, orientation, and lithology of the coalfield. The basic statistical information is listed in Table 1. Fault detection was accomplished by calculating the dip angle and dip direction at unobserved locations on a regular grid. The data describing the coal seam roof and floor was obtained from drill hole logs. The developed dataset was used as an input to GEOVIA Surpac, and the ore body modeling accomplished by the triangulation method was performed. Firstly, surface models on coal seam roof elevations were established. The surface was then gridded into equal squares and equally divided into four parts. Then the values for the x, y, and z coordinates and the maximum dip of each point were determined. From the corresponding surface readings, elevations of corner points of the squares were obtained, and the maximum dip and dip direction representing each square were computed using the Microsoft Excel-based algorithm. For a typical square, Equation 1 was used to calculate the dip angles of 30 different lines. Consequently, for a typical square, the line with maximum dip was found. The azimuth angle (dip direction) of each line was found using Equation 2. The subscripts 1 and 2 in Equations 1 and 2 refer to the starting and ending points of the line, respectively. The maximum dip value and its azimuth were recorded as the dip and dip direction angles of that square.

$$\text{Dip} = \tan^{-1}\left(\frac{z_2 - z_1}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}\right) \quad (1)$$

$$\text{Dip Direction} = \cos^{-1}\left(\frac{\sin y_2 - \sin y_1 \times \cos d}{\sin d \times \cos y_1}\right) \quad (2)$$

Figure 4 shows the line connecting the pole points of a sample square. The calculated maximum dip and dip direction values were used to obtain block models for fault detection in GEOVIA Surpac. The block models that contained data of maximum dip and dip direction was prepared, and the variations around fault zones were estimated by the inverse distance squared weighted (ID^{2}W) interpolation. The change in elevation was observed around the fault zone. The fault zones created from the block models obtained were matched with the pre-existing fault lines based on aerial maps. The general workflow of modeling can be divided into the following steps:

1. Creating a drill hole database
2. Creating top surfaces of the coal seams
3. Gridding surfaces
4. Determining elevations
5. Calculating the dip angle and dip direction
6. Creating a block model
7. Estimating unknown points by the ID^{2}W interpolation technique

The fault zones that change the continuity of geological structures were investigated. The dip calculation was found to be an essential and useful variable for the indication of faults. The individual dip maps generated for each coal seam are shown in Figures 5, 6, and 7. The distinction between generated fault zones and pre-existing fault lines is indicated by superimposing (overlapping) the fault lines. The dip angle describing the steepness of the fault surface has a series of direction from vertical to horizontal. Noticeable variances in dip and dip direction are graphically observed between the pre-existing fault lines and the generated models in the figures. The fault line on the dip angle map of the main Sonda seam is marked, which indicates a fault in the north direction (Figure 6 b). Similar disconformity (presented as a dotted line in Figure 7b) is also observed on the dip direction map. Because of this evaluation, two major faults developed orthogonally were indicated within the studied area (shown in Figure 8).

Table 1. Basic statistics of data.

Seam	No. of occurrence	Average thickness (m)	Average depth from mean sea level (m)
Sohnari (SOH)*	7	0.609	-30.756
Daduri One (D1)	18	0.543	-90.326
Daduri Two (D2)*	8	0.434	-105.899
Upper Strays (USTR)	28	0.682	-122.341
Inayatabad (I)	23	0.978	-138.076
Sonda Upper (SU)	25	1.084	-170.502
Sonda Main (S)	61	1.621	-162.737
Sonda Lower Main (SSL)	18	1.361	-198.246
Sonda Lower (SL)*	5	0.49	-164.728
Wassi (W)	15	0.878	-210.733
Lower Strays (LSTR)*	6	0.738	-239.242
Jherruck (J)*	2	1.57	-264.995

*seam not modeled due to less occurrence in the drill holes and inadequate data.

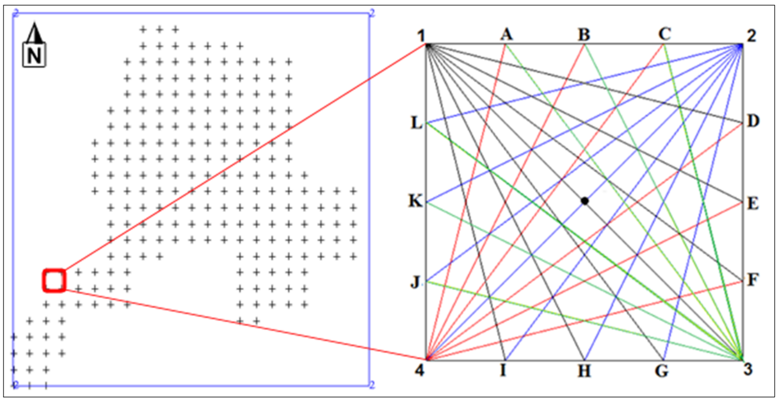

Figure 4. The lines connecting pole points of a sample square.

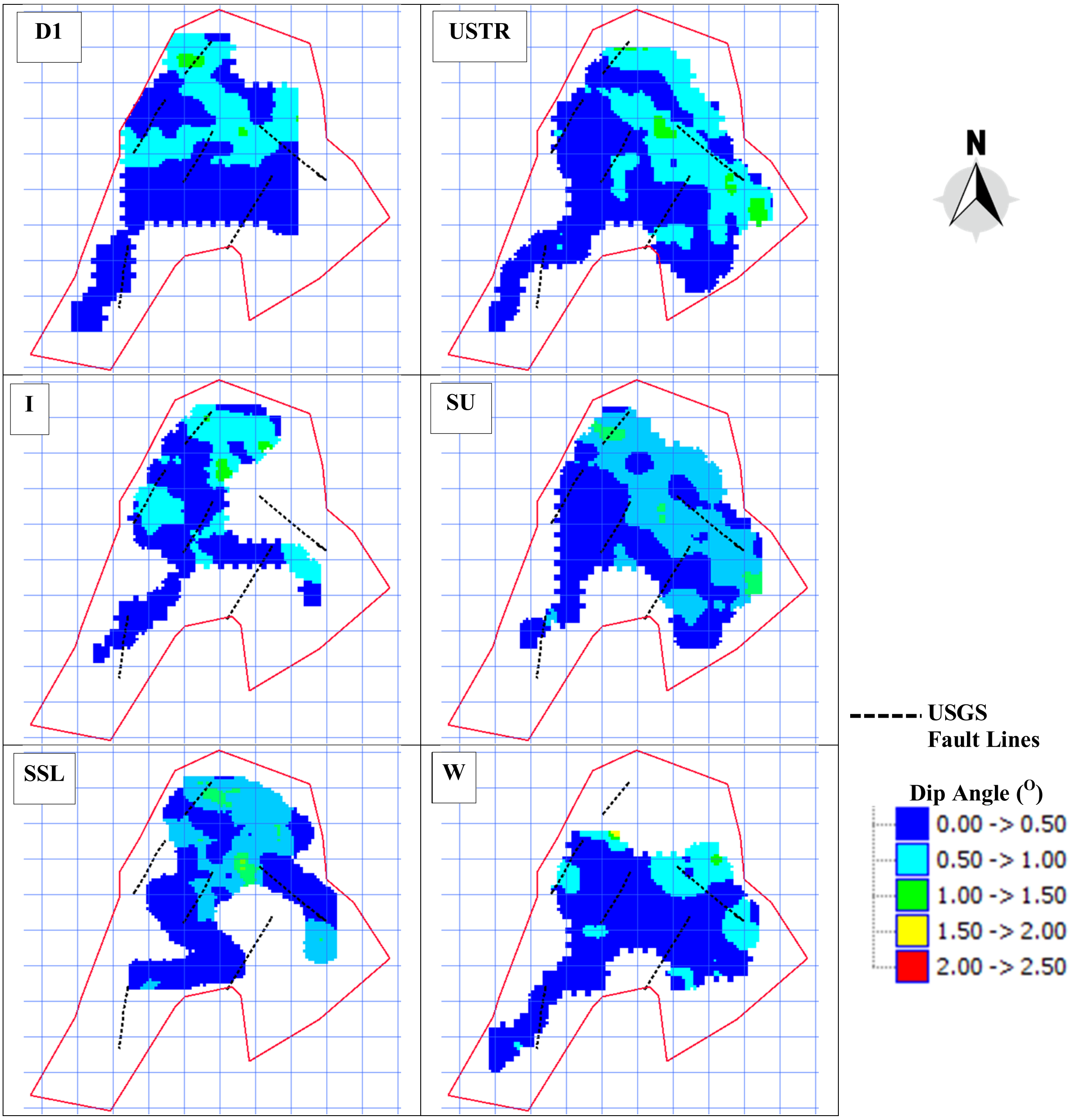

Figure 5. Block models of potential fault zones in the study area.

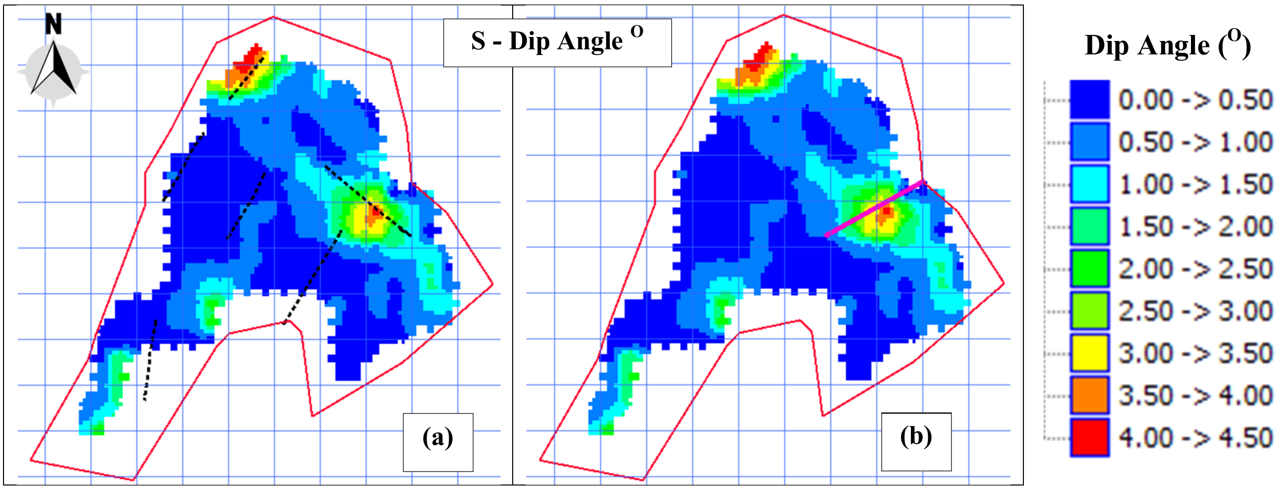

Figure 6. Block models of fault zones in the main Sonda seam (based on dip angle).

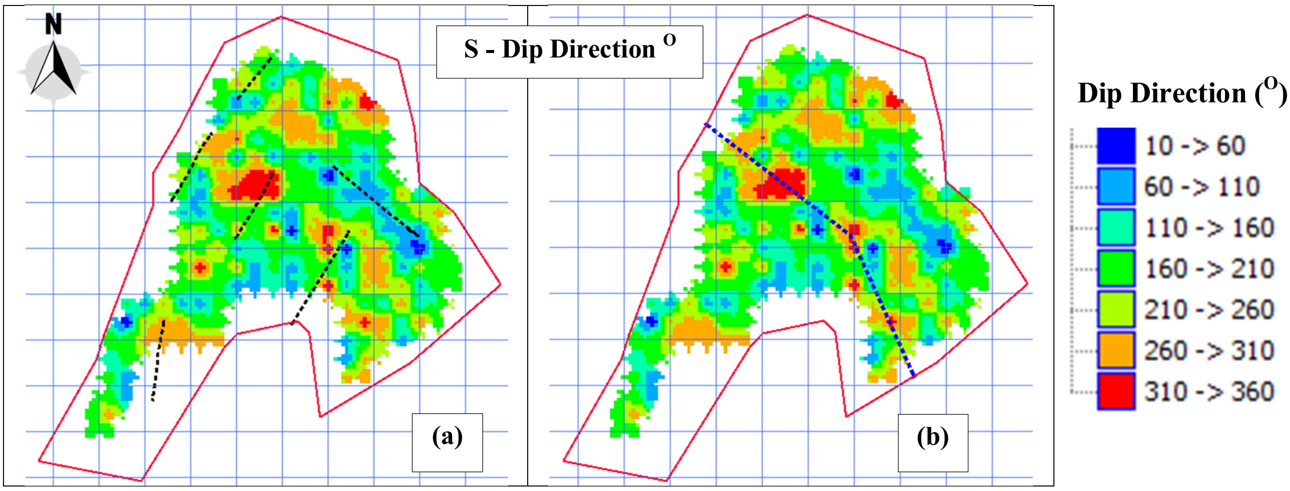

Figure 7. Block models of fault zones in the main Sonda seam (based on dip direction).

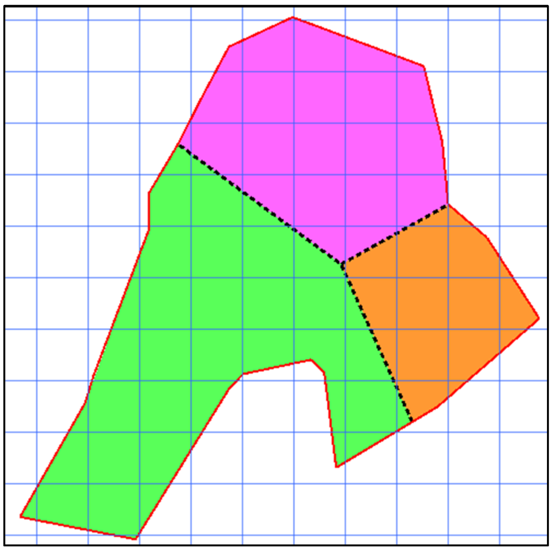

Figure 8. The coalfield separated by fault zones.

4. Conclusions

The sever energy crisis has seriously affected Pakistan's industrial and socio-economic development, so the sustainability concerns of industrial development are increasing towards coal. The Sonda-Jherruck coalfield has a great potential in building new thermal power plants. The quality of lignite coal is also capable of being used for power generation. Therefore, it is required to implement more effective, quantitative, and practical methods for the assessment of geological faults in order to better plan mining operations. Appropriate resource planning based on reliable geological models enables mine management to focus on value-generating tasks. This work has attempted to outline a method for quantifying and predicting faults. Drill hole data and dip values are important variables for determining potential fault zones. The ID^2W interpolation technique was used to investigate fault patterns that change the continuity of geological structures of the field. In this work, we highlighted the major fault zones in the studied area and proposed a method to improve the previously determined fault lines using modern computer-aided modeling software. The generated 3D models can be helpful in determining the boundaries for volume calculation in order to obtain appropriate mine plans. One conclusion drawn from the use of drill hole data in any detailed resource assessment study is that the reliability of interpretation strongly depends on drill hole spacing and coal seam correlation. The fault detection method described in this paper can be more effectively used to determine the fault pattern in the closely spaced and well-defined drilling area. The results obtained recommend that it was necessary to carry out a detailed exploration project with the purpose to understand the characteristics of geological fault zones and explore its relationship with mineralogy. This research work will help to develop the essential capabilities of mine planning and design; hence, steps can be taken for ensuring steady development.

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مدل‌سازی جهت گسل در منطقه زغال‌سنگ Sonda- Jherruck در کشور پاکستان

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چکیده:

گسل‌ها مهم‌ترین عوامل تکتونیکی در ساختارهای زمین‌شناسی هستند که تأثیر عمده اقتصادی بر اقتصاد معدن دارند؛ بنابراین برای شناسایی خطرات و پیچیدگی‌های واقعی مرتبط با معدن لازم است که گسل‌ها به خوبی شناسایی شوند. در بررسی‌های مقدماتی در منطقه زغال‌سنگ Sonda- Jherruck، مدل‌های سه‌بعدی زمین‌شناسی اجرا نشده بود. هدف از این پژوهش، انجام مدل‌سازی جهت‌گیری گسل به منظور تکمیل اطلاعات برنامه‌ریزی معدن و بحث در مورد موانعی است که می‌تواند مشکلات در برنامه‌ریزی و مراحل توسعه را ایجاد کند است. با استفاده از داده‌های گمانه‌های حفاری، مدل سه‌بعدی گسل‌ها بر اساس محاسبه زاویه شیب و شیب ایجاد شد. در مرحله اول، مدل‌های سطحی لایه‌های زغال‌سنگ با استفاده از روش مثلثی ایجاد شد. سپس یک شبکه مناسب به هم پیوسته برای تنظیم داده‌ها و پیدا کردن نقاط ناشناخته استفاده شد. محاسبه شیب و جهت شیب با استفاده از یک الگوریتم انجام شد. مدل‌ها نشان داد که تغییرپذیری در شیب و جهت شیب با استفاده از روش درون‌یابی وزن دهی عکس مجذور فاصله تولید شده است. مدل‌های سه‌بعدی تولید شده با خطوط گسل از قبل موجود (بر اساس نقشه‌های هوایی) مقایسه شد. این پژوهش برای ایجاد مدل‌های جامع که درک بهتری از گسل‌های موجود در منطقه مورد مطالعه را نشان می‌دهد انجام شده است.

کلمات کلیدی: ساختار زمین‌شناسی، مدل‌سازی سه‌بعدی زمین‌شناسی، جهت گسل، شیب، جهت شیب.