MULTIVARIATE AND SPATIAL STATISTICAL ANALYSIS OF GEOCHEMICAL DATA OF DOLOMITE: THE CASE OF INDUSTRIAL RAW MATERIALS' DIFFERENTIATION

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Abstract. Dolomite, which is a carbonate rock formed with a sufficient source of magnesium, may have different genesis and types. Various geochemical and statistical methods are used to determine these differences. In this study, dolomite samples were collected from the Obaalacami site in the Alanya district of the Antalya province (Turkey). The study aims to reveal the differences in the geochemical properties of dolomite samples in terms of their genesis and existence using multivariate and spatial statistical analyses. Therefore, multivariate statistics and spatial analysis methods were used. The mineralogical properties of the samples collected from the field were determined by conducting XRD analysis. It was found that 90% of the mineralogical content of the samples consisted of dolomite mineral and the remaining 10% consisted of calcite. Thin cross-sectional images revealed that calcite mineral was found in the recrystallized form. The dolomite samples, which were geochemically classified under three groups, were found to have similar elemental contents by using statistical methods (distribution maps, heat maps, and cluster analysis). The samples classified as Type-1 dolomite (medium-crystalline dolomite) were found to have high concentrations of MgO in their composition while the samples classified as Type-2 dolomite (micritic fine-crystalline dolomite) had high concentrations of CaO and Zr content. On the other hand, the samples classified as Type-3 dolomite (dolarenite dolomite) were found to have high concentrations of Al_2O_3, SiO_2, Fe_2O_3, and Sr compounds. The mathematical model of the regression analysis for the formation of dolomites in the region was found to be (%) SiO_2 = -0.1 + 31.92 * (%) Sr + ϵ (R^2 = 0.97, P-value =0). Multivariate and spatial statistical methods conducted to interpret geochemical data revealed that dolomitic formations in the region had different genesis and types. The interpretations regarding the genesis and types of the dolomites provide parameters that can be effectively used in determining the industrial use of dolomites. The multivariate statistical and spatial analysis methods conducted in the study can be easily used to obtain the geochemical properties of various metallic mines and various industrial raw materials, their spatial distributions, and the differences in terms of their genesis.

Keywords: Multivariate statistics, spatial statistics, applied mathematics, dolomite.

MSC(2010): 62H10, 62H05

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1. Introduction

It is known that carbonate rocks are formed at various stratigraphic intervals under diagenetic conditions [10]. The fact that the rocks have a porous, fractured, and hollow structure and the presence of diagenetic minerals (dolomite, quartz, calcite, etc.) in the rock provide the suitable conditions for the formation of dolomite [25],[53],[26]. The natural stones that are important in terms of industrial raw materials and have more than 20% MgO content as a result of the diagenesis process of limestones are called dolomite [1]. As a natural rock, dolomites can form mostly in lakes, shallow seafloors, saline water interference areas, and low-relief evaporitic basins [1]. The formation of dolomite ores depends on geological and environmental factors. In marine basins, these dolomite ores can form by evaporation of water and precipitation of calcium carbonate in the environment [3], [52]. The sufficient source of Mg (Magnesium) and the presence of porous rocks provide the chemical condition for the formation [1], [21]. Statistical analyses and mathematical modeling studies using the geochemical data of the major and trace elements that constitute dolomite facilitates making interpretations about the nature and genesis of diagenetic fluids [53].

In the literature, various studies have been conducted using statistical and mathematical methods to examine the geochemical analysis results of dolomite ores. In the study carried out to determine the types of dolomites in Southern Missouri, the genesis and types were identified using multivariate statistical methods of points in hyper-dimensional space, factor analysis, and discriminant function [29]. In another study, the geochemical properties of the dolomite ores in Northern Italy were analyzed. The descriptive statistics and bivariate diagrams of the analysis results shed light on the interpretations about the genesis and type of the ores studied in this study [28]. The dolomite samples collected from the Razzak oil field in Egypt were studied to determine their geochemical properties. The descriptive statistics of the analysis results were used to classify these dolomite samples [22]. The statistical approaches were applied to geochemical data in a study, which was carried out to investigate the formation of the paleo-sedimentary depositional environment in Iran. In this study, the scatter plots, Pearson's correlation coefficients (r), and level of statistical significance (p) values were calculated [1]. In a study conducted using 89 samples collected from dolomites observed in Chuping formation in Malaysia, geochemical data were interpreted by use of their descriptive statistics. Significant information has been obtained about the genesis and formation processes of dolomites [1].

Several physical and chemical properties of dolomites from the Polish plain were determined. The researchers studied the relationships between type, variety, and genesis of the reservoir by evaluating the characteristics using the statistical analysis method [23]. Odisha Gomardih dolomites (India), which were found to have low-grade content, were studied using

geochemical analysis methods. The statistical explanation and accuracy of the new geochemical properties gained by the dolomite samples after being subjected to the enrichment process were tested [30]. During the geochemical studies of the Ordos basin dolomites (China), the descriptive statistics of the data provided a clue about the genesis of the natural gas outflows in the region [8]. The effect of the rare earth element (REE) concentrations of dolomite samples on formation and genesis was investigated using multivariate statistical methods [9], [14], [5], [16].

The dolomite ore in the Obaalacami site in the Alanya district of the Antalya province (Turkey/SW) is located approximately 10 km inland from the coastline of Alanya harbor (Fig. 1). The study area is bounded by the Alanya peninsula on the west and Alanya Bay on the east. In the literature, there is no study on the geochemical properties of dolomites extracted from the Obaalacami site, as well as, analyzing and explaining these properties using multivariate and spatial statistical methods. The international literature review on the subject revealed that no scientific study was made on the detailed interpretation of the geochemical properties of dolomites using multivariate and spatial statistical methods. The present research will make a significant contribution to the national and international scientific studies on the properties of dolomites.

In this context, the study aimed to determine the contents of the dolomite formations in the region (XRF analysis), to identify dolomites (Alizarin red analysis, XRD, and thin cross-sectional analysis), and to explain and interpret geochemical properties of dolomites using multivariate statistical methods (descriptive statistics, correlation, regression, factor, and cluster analyses), and spatial statistical (distribution maps) methods. The reason for the geochemical differentiation observed in dolomites was explained based on a mathematical model of regression analysis by using these methods.

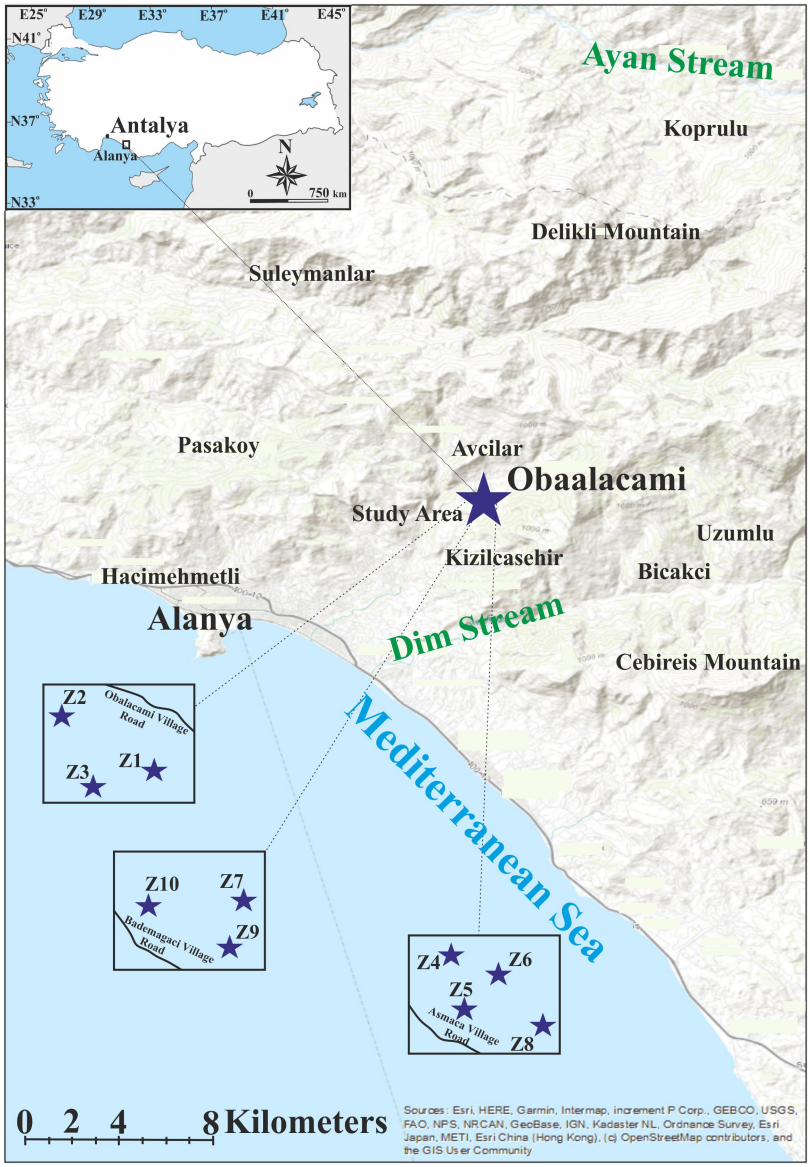


FIGURE 1. Site location map of the study area and the locations of the samples.

2. MATERIALS AND METHODS

2.1. **Geochemical Analysis.** The dolomite samples collected from the Obaalacami site were brought to the Geological Engineering Department of the Engineering Faculty at Akdeniz University. Firstly, ten dolomite samples, which were thought to be representative of the region, were ground

to a clay size (< 0.002 mm). One gram of each ground sample was subjected to the loss of ignition (LOI) analysis. The results of the LOI analysis are important for the calculation of the geochemical data [37]. In order to calculate the loss of ignition values, the samples collected from the field were kept in an ash oven at 1000°C under hygienic laboratory conditions for 4 hours. The LOI values were calculated by determining the mass losses of the samples (Table 1) [11].

The ground samples were subjected to a sample preparation process before analyzing them using the X-Ray fluorescence spectrometry (XRF). The samples were subjected to the pellet making process, and press-pastilles were produced from these pellets under 30 MPa pressure using a hydraulic press machine [17]. The pellets obtained by adding 2 grams of boric acid to 4 grams of samples were analyzed using an XRF device to determine their elemental composition. Rigaku NEX CG energy dispersive X-ray fluorescence spectrometer (NEX-CG Applied Rigaku Technologies, Inc. Austin, TX, USA) with an artificial X-ray tube of 50W was used in the analyses.

The Alizarin and XRD analyses, as well as the thin cross-sectional examinations, were carried out to reveal the mineralogical and petrographic properties of dolomite samples in detail. The Alizarin analyses and the thin cross-sectional examinations were carried out in the General Directorate of Mineral Research and Exploration (Ankara) while the XRD analyzes were performed using Rigaku D/MAX 2200 PC XRD device in the Geological Engineering Department at Hacettepe University [11].

2.2. **Statistical Analysis.** Geochemical analysis data were interpreted using the results of the multivariate statistical analyses. The following statistical analyses were conducted in the present study: descriptive statistics, correlation analysis, factor analysis, and cluster analysis. The SPSS23 software package was used to conduct statistical analyses.

2.3. **Spatial Statistics.** The coordinates of the samples collected from the field are arranged as longitude (X) and latitude (Y) in decimal degrees. The coordinates arranged were imported to ArcGIS 10.6.1 software together with geochemical analysis data. Then, the coordinates of the samples were added to the raster map covering the Alanya region. The spatial distribution maps of the geochemical data were generated using the Kriging interpolation method Fig. 2.

3. Results and Discussion

The results of the geochemical analysis of the samples and the geographical coordinates (latitude and longitude in decimal degrees) of the locations where the samples were collected are given in Table 1.

3.1. **Distribution Maps.** The distribution maps of geochemical data, which were generated using the ArcGIS 10.6.1 software, were presented in Fig. 2 (a, b, c, d, e, f, g).

TABLE 1. Elemental concentration of the dolomites area [11].

	Lat.	Long.	MgO	Al_2O_3	SiO_2	CaO	Fe_2O_3	Sr	Zr	Descr.	LOI	TOTAL
Z1	36.58956	32.09773	18.7	0.345	0.354	33.9	0.0346	0.0138	0.254	Type-3	46.3	99.8876
Z2	36.58940	32.09735	39.1	0.079	0.013	16.6	0.0134	0.0028	0.178	Type-1	43.9	99.8834
Z3	36.58894	32.09751	14.4	0.112	0.0498	32.9	0.0094	0.0040	0.0263	Type-3	52.2	99.6975
Z4	36.58848	32.09765	19.9	0.136	0.0516	35.8	0.0118	0.0049	0.252	Type-3	43.7	99.8514
Z5	36.58816	32.09775	25.9	0.111	0.0739	29.8	0.0115	0.0063	0.246	Type-1	43.8	99.9424
Z6	36.58793	32.09809	15.8	0.115	0.0455	40.2	0.0105	0.0051	0.302	Type-2	43.5	99.9781
Z7	36.58769	32.09790	16.1	0.116	0.0497	40.1	0.0102	0.0045	0.3	Type-2	43.3	99.9759
Z8	36.58771	32.09844	19.8	0.138	0.0166	35.7	0.0121	0.0039	0.316	Type-3	44	99.9827
Z9	36.58741	32.09782	19.2	0.103	0.035	35.3	0.0096	0.0041	0.276	Type-3	45	99.9277
Z10	36.58765	32.09735	16.7	0.109	0.061	34	0.0105	0.0048	0.211	Type-3	48.8	99.6805

*Type-1: Medium crystalline dolomite, Type-2: Micrite-fine crystalline dolomite, Type-3: Dolarenite.

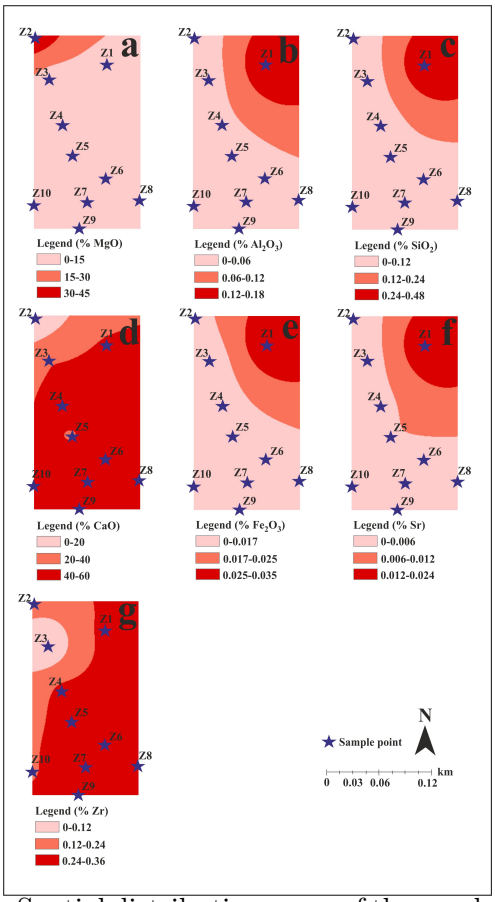


FIGURE 2. Spatial distribution maps of the geochemical data (MgO, Al_2O_3, SiO_2, CaO, Fe_2O_3, Sr, and Zr).

The following results were obtained from the spatial distribution maps generated using the coordinates of the samples collected from the study area:

1. The spatial distributions of Al_2O_3, SiO_2, Fe_2O_3, and Sr, which are the major and trace geochemical compounds (Type-3), in the dolomite field were found to be directly proportional.

2. The spatial distributions of Sr and Zr, which are the major and trace geochemical compounds (Type-2), in the dolomite field were found to be directly proportional.

3. It was observed that MgO, which is one of the major geochemical compounds (Type-1), did not show a direct proportional distribution with any other major and trace geochemical compounds; however, it showed an inversely proportional spatial behavior.

3.2. **Multivariate Statistical Analysis.**

3.2.1. *Descriptive Statistics.* Table 2 presents the descriptive statistics of the geochemical data. The mean values of the geochemical contents of dolomite samples in the descending order are as follows: CaO (33.43±2.11) > MgO (20.56±2.29) > Zr (0.23±0.02) > Al_2O_3 (0.13±0.023) > SiO_2 (0.07±0.031) > Fe_2O_3 (0.013±0.002) > Sr (0.005±0.0009).

TABLE 2. Elemental concentration of the dolomites area [11].

	MgO	**Al_2O_3**	**SiO_2**	**CaO**	**Fe_2O_3**	**Sr**	**Zr**
Mean	20.56±2.29	0.13±0.023	0.07±0.031	33.43±2.11	0.01±0.002	0.005±0.0009	0.23±0.02
Median	18.95	0.11	0.04	34.6	0.01	0.004	0.25
Mode	14.4a	0.07a	0.01a	16.6a	0.01	0.002a	0.02a
STD (σ)	7.25	0.075	0.09	6.68	0.007	0.003	0.085
Skewness	2.19	2.87	2.95	-1.94	3.01	2.66	-1.87
Kurtosis	5.22	8.73	9.07	4.91	9.28	7.724	4.12
Minimum	14.4	0.079	0.013	16.6	0.009	0.002	0.026
Maximum	39.1	0.34	0.35	40.2	0.03	0.01	0.31

a. Multiple modes exist. The smallest value is shown

The standard deviations of the samples were found to be smaller than their arithmetic mean. In this context, it could be interpreted that the geochemical properties of the samples did not diverge from the average and that they were close to each other [45], [43]. The outliers among the geochemical properties of the samples were tested using the box-plot analysis (Fig. 3). The box plots provided information about the central tendency and prevalence of geochemical properties. If the median line is observed to be below the center in the box plot, the distribution is regarded to be positively skewed. If it is above the center, the distribution is negatively skewed. If the median line is right in the middle, the distribution is regarded to be normal [13], [42], [37]. The distribution of MgO, which is one of the major geochemical compounds in dolomite, was found to be between 15-20% in the samples. The two samples that deviated from the mean value and differed from other samples were found to be Z2 and Z5. The median line was observed to be above the box. Therefore, the distribution of MgO could be interpreted to be negatively skewed (Fig. 3-a).

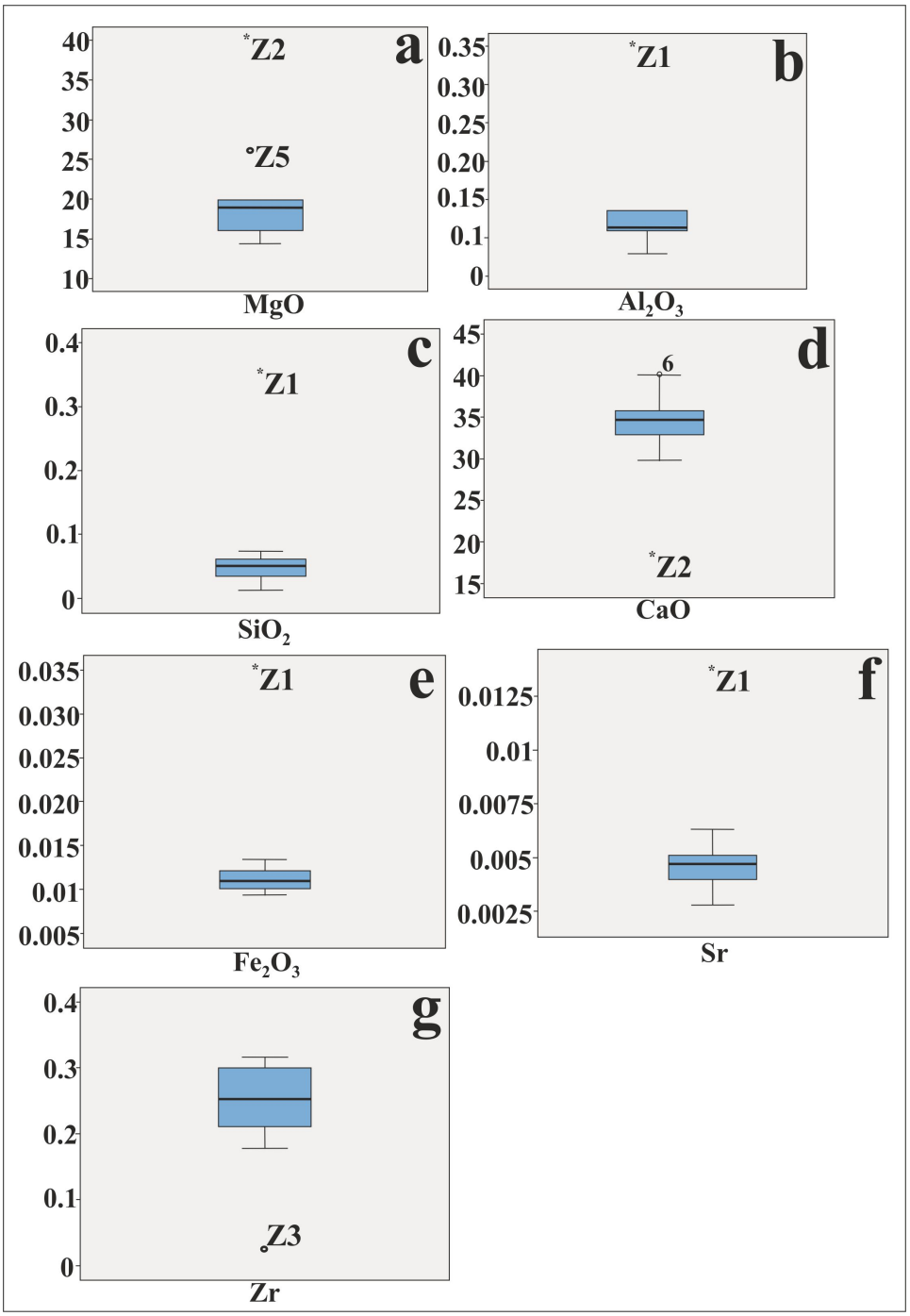


FIGURE 3. Box plots of the geochemical data.

The distribution of Al_2O_3, which is one of the major geochemical compounds in dolomite, was found to be between 0.1-0.15% in the samples. The sample that deviated from the mean value and differed from other samples was found to be Z1. The median line was observed to be below the box. Therefore, the distribution of Al_2O_3 could be regarded to be positively skewed (Fig. 3-b).

The distribution of SiO_2, which is one of the major geochemical compounds in dolomite, was found to be between 0-0.1% in the samples. The sample that deviated from the mean value and differed from other samples was found to be Z1. The median line was observed to be above the box. Therefore, the distribution of SiO_2 could be regarded to be negatively skewed (Fig. 3-c).

The distribution of CaO, which is one of the major geochemical compounds in dolomite, was found to be between 30-40% in the samples. The sample that deviated from the mean value and differed from other samples was found to be Z2. The median line was observed to be above the box. Therefore, the distribution of CaO could be regarded to be negatively skewed (Fig. 3-d).

The distribution of Fe_2O_3, which is one of the major geochemical compounds in dolomite, was found to be between 0.01-0.015% in the samples. The sample that deviated from the mean value and differed from other samples was found to be Z1. The median line was observed to be below the box. Therefore, the distribution of Fe_2O_3 could be regarded to be positively skewed (Fig. 3-e).

The distribution of Sr, which is one of the trace geochemical compounds in dolomite, was found to be between 0.0025-0.0075% in the samples. The sample that deviated from the mean value and differed from other samples was found to be Z1. The median line was observed to be above the box. Therefore, the distribution of Sr could be regarded to be negatively skewed (Fig. 3-f).

The distribution of Zr, which is one of the major geochemical compounds in dolomite, was found to be between 0.2-0.3% in the samples. The sample that deviated from the mean value and differed from other samples was found to be Z3. The median line was observed to be below the box. Therefore, the distribution of Zr could be regarded to be positively skewed (Fig. 3-g).

In the study conducted with 60 samples collected from the dolomite field in Southern Missouri, the ranges of the $MgCO_3$ and $CaCO_3$ contents in the dolomites were found as follows: (%) (33.04-48.29); (50.17-57.93) [29].

According to the results of the geochemical analysis of dolomite samples collected from Northern Italy, the ranges of the MgO and CaO contents were found as follows: (%) (11.75-18.49); (17.51-26.06) [28].

According to the results of the geochemical analysis of the samples collected from the dolomites in the Razzak oil field in Egypt, the mean values of the MgO and $CaCO_3$ contents were found to be 49.10% and 50.6%, respectively [22].

According to the results of the geochemical analysis of the dolomite samples collected from the Aydincik region in Mersin (Turkey), the ranges of the MgO and CaO contents were found to be (%) (19.01-22.26) and (28.78-33.37), respectively [7].

In the study conducted on dolomites in the Southern Apennines region (Italy), geochemical analysis of dolomites was conducted, and the ranges of the CaO content were found to be 49.6% and 56.2%, respectively [10].

The results of the chemical analysis of dolomite samples collected from Malaysia revealed that the ranges of the MgO and CaO contents were (%) (0.46-19.54) and (32.85-47.58), respectively [1].

According to the results of the chemical analysis of dolomite powders collected from the Gomardih minefield in Odisha (India), the mean values of the geochemical compounds of CaO, MgO, SiO_2, and Al_2O_3 were found to be %28.6, %20.1, %8.3, and %1.5, respectively [30].

The results of the geochemical analysis of 19 samples collected from the Ordos basin dolomites in China, the ranges of the MgO and CaO compounds were found to be (%) (16.1-23.6) and (22.4-32.9), respectively [8].

As one of the descriptive statistics, kurtosis value describes the shape of the distribution, and it is related to the flatness or peakedness of a distribution curve. While negative values mean that the curve has a flat shape, positive values mean that the curve has a peaked shape [13], [38] (Fig. 4). The kurtosis values of the geochemical data were found as follows in descending order: Al_2O_3 (9.28) > SiO_2 (9.07) > Al_2O_3 (8.73) > Sr (7.72) > MgO (5.22) > CaO (4.91) > Zr (4.12).

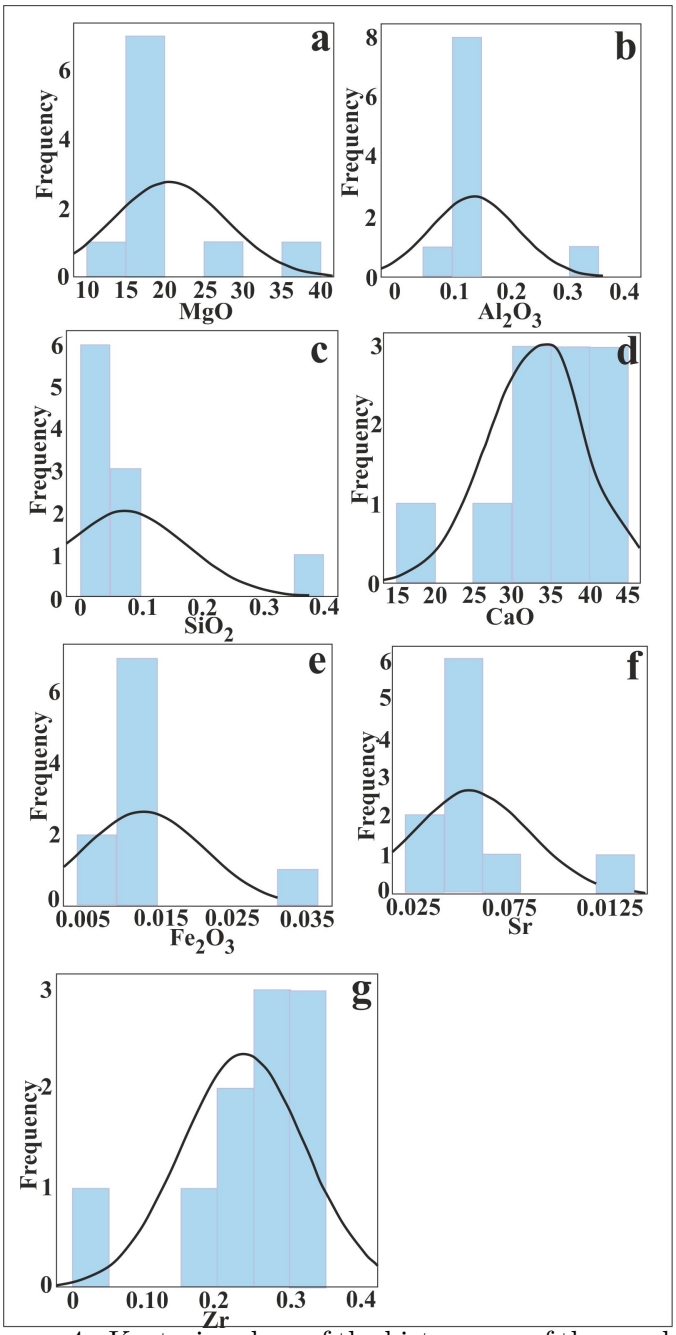


FIGURE 4. Kurtosis values of the histograms of the geochemical data [11]

Considering the histograms of all the geochemically analyzed compounds, it was found that the curves had peaked forms (Fig. 4-a, b, c, d, e, f and g). On the other hand, the skewness value, which is another measure of

the distribution shape, may range between -∞ and +∞. The distribution is assumed to be normal when the skewness is between the values of -3 and 3 [13], [34]. The skewness of the distribution of the geochemical data was observed to be in the range between -3 and 3 (Table 1).

3.2.2. *Correlation Analysis.* In order to determine the negative and positive correlations in the geochemical data, the dataset was first tested whether it provided the assumption of normality or not [19], [44] (Table 3). Normality tests are checked by the P-value regarding the significance of the Z statistic [33]. The method to be preferred for the test of normality is determined considering the number of samples [19]. If the sample size is n < 30, the Shapiro-Wilk test should be used; if it is n≥30 then the Kolmogorov-Smirnov test should be used, and the corresponding P-value should be checked [6], [19], [33]. In the present study, the Shapiro-Wilk test was used to test the normality of the geochemical analysis results of dolomite samples. The hypotheses established for the normality test are as follows:
H_0: Geochemical data provide the normality condition.
H_a: Geochemical data do not provide the normality condition.

TABLE 3. Normality test results of the geochemical data [11]

	Tests of Normality					
	Kolmogorov-Smirnova			**Shapiro-Wilk**		
	Statistic	df	**P-value**	Statistic	df	**P-value**
MgO	0.33	10	0.002	0.73	10	0.003
Al_2O_3	0.39	10	0.000	0.57	10	0.000
SiO_2	0.40	10	0.000	0.54	10	0.000
CaO	0.26	10	0.040	0.79	10	0.011
Fe_2O_3	0.39	10	0.000	0.51	10	0.000
Sr	0.34	10	0.002	0.64	10	0.000
Zr	0.24	10	0.087	0.81	10	0.020

a. Lilliefors Significance Correction

According to the results of the Shapiro-Wilk test, the P-value was found to be below 0.05. This revealed that the data were not normally distributed at the significance level of 5%. Thus, the Ha hypothesis, which was the alternative hypothesis of the H_0 hypothesis, was accepted. The correlations between the data, which were found to be not normally distributed according to the results of the normality test, were analyzed using Spearman's rank-difference correlation coefficient [26] (Table 4). Spearman's rank-difference correlation is calculated using equation (3.1) [33].

$$\rho = 1 - \frac{6\Sigma d_i^2}{n\left(n^2-1\right)} \tag{3.1}$$

256

$$\begin{aligned} \rho &= \text{Spearman's rank difference} \\ d_i &= \text{Difference between the ranks of the variable} \\ n &= \text{Number of samples} \end{aligned}$$

TABLE 4. Results of Spearman's correlation analysis of geochemical data [11]

	MgO	**Al_2O_3**	**SiO_2**	**CaO**	**Fe_2O_3**	**Sr**	**Zr**
MgO	1						
Al_2O_3	-0.212	1					
SiO_2	-0.152	0.333	1				
CaO	-0.430	0.467	-0.152	1			
Fe_2O_3	0.638*	0.353	0.079	-0.243	1		
Sr	-0.115	0.394	0.818**	0.176	0.176	1	
Zr	-0.115	0.527	-0.273	0.770**	0.091	0.139	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

257 Although MgO was found to have a negative correlation with other major
258 and trace elements, it had a low-order moderate positive correlation with
259 Fe_2O_3. A strong positive correlation was found between SiO_2 and Sr. On the
260 other hand, a high-order moderate positive correlation was found between
261 CaO and Zr. According to the results of the correlation analysis, it was con-
262 cluded that the two major compounds, MgO and CaO, which contributed
263 the most to the formation of dolomite, were found to have a negative corre-
264 lation. It was interpreted that the dolomitization in the region did not have
265 a sedimentary genesis.

266 3.2.3. *Regression Analysis.* The enrichment in the CaO concentration dur-
267 ing diagenesis reactions causes depletion in Sr. The formation of dolomites
268 depends on the amount of MgO and CaO in the environment. In this con-
269 text, the enrichment in the MgO and CaO in the environment causes deple-
270 tion in SiO_2, which is a rock-forming compound. Considering its correlation,
271 the statistical explanation of the SiO_2-Sr relationship, which was observed
272 to be a highest-order positive correlation, was tested (Fig. 5) [2].

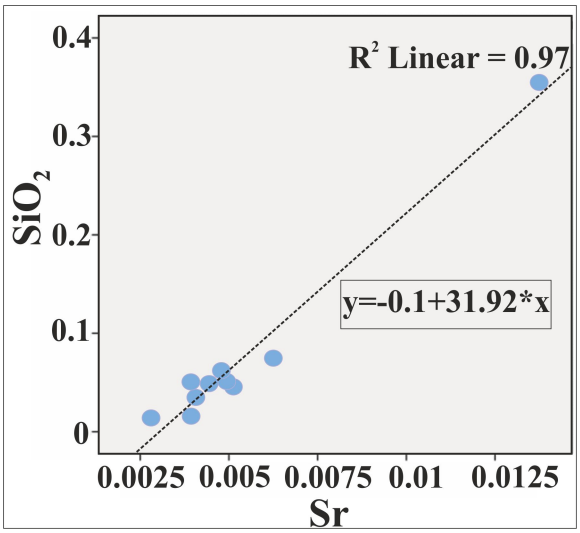


FIGURE 5. Linear plot of the SiO_2-Sr distribution [11]

The correlation analysis confirmed the linear correlation between SiO_2 and Sr. A high-degree strong positive correlation was found between them. The linear correlation between Sr and Sr was summarized using the following mathematical regression model (3.2):

$$(\%)\mathrm{SiO_2} = -0.1 + 31.92 * \mathrm{Sr}(\%) + \epsilon(\text{Regression Model}) \tag{3.2}$$

Linear regression analysis was conducted for the SiO_2-Sr relationship, which was observed to have a linear positive correlation (Table 5, Table 6).

TABLE 5. Regression model summary table.

Model Summary[b]

Model	R	R Square	**Adjusted R Square**	Std. Error of the Estimate
1	0.98_a	0.97	**0.97**	0.01

a. Predictors: (Constant)0. Sr
b. Dependent Variable: SiO_2.

TABLE 6. Analysis of variance table.

ANOVA[a]

	Model	Sum of Squares	df	Mean Square	F	**P-value**
	Regression	0.08	1	0.08	2870.18	$\mathbf{0_b}$
1	Residual	0.002	8	0		
	Total	0.09	9			

a. Dependent Variable: SiO_2
b. Predictors: (Constant)0. Sr

The coefficient of determination (explained variance) table (R^2) reveals that 97% of SiO_2 content can be explained by Sr or that 97% of the Sr content can be explained by the SiO_2 content. The P-value in ANOVA analysis shows the error rate/variance of the statistic [40], [50], [48], [47], [46], [51], [4], [35], [49], [20]. The mathematical model of the regression analysis that explained the SiO_2-Sr correlation was found to be significant. The parameter estimates (coefficients) of the mathematical model of the regression analysis for the SiO_2-Sr correlation are presented in (Table 7).

TABLE 7. Parameter estimates.

Coefficientsa

Model		Unstandardized Coeff.		Standardized Coeff.	t	P-value	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant) (b_0)	**-0.09**	0.01		-8.44	**0**			
	Sr (b_1)	**31.92**	1.88	0.98	16.94	**0**	0.98	0.98	0.98

a. Dependent Variable: SiO_2

The B constant values in the parameter estimates table are the points where the line intersects the y-axis. The P-values were found to be statistically significant since they were below 0.5. The fact that b_1 was found to have a positive value indicated that it had a positive linear correlation with b_0 [13], [38]. The partial derivatives of the regression model were calculated with respect to the variables of b_0 and b_1. The values with which the partial derivatives equaleṭo 0 were calculated to find the optimal values that minimize the regression model equations: (3.3), (3.4) and (3.5) [13]. The regression parameters of the mathematical model established could be explained at the significance level of 5%.

$$\frac{\partial}{\partial b_1}\sum_{i=1}^{n}(y_i - b_0 - b_1 x_i)^2 = 0 \tag{3.3}$$

$$b_1 = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})} \tag{3.4}$$

$$b_0 = \overline{y} - b_1\overline{x} \tag{3.5}$$

x_i = i^{th} observation value of the independent variable
y_i = i^{th} observation value of the dependent variable
$\overline{x}$ = mean value of the independent variable
$\overline{y}$ = mean value of the dependent variable

3.2.4. *Factor Analysis.* In order to reveal the relationship between the geochemical data and to classify the data, factor analysis was conducted [13], [44], [36], [18],[19]. The suitability of the data for the factor analysis should be tested before performing the analysis [13], [33]. Therefore, the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were applied to determine the suitability of the data for the factor analysis (Table 8).

TABLE 8. Kaiser-Meyer-Olkin Measure of Sampling Adequacy of the geochemical data.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.51
Bartlett's Test of Sphericity	Approx. Chi-Square	97.51
	df	21
	P-value	**0**

According to the KMO value ($0.51 > 0.5$), the geochemical data were considered to be adequate for factor analysis [24]. Moreover, the result of Bartlett's test of sphericity was calculated as 97.51, and the P-value was found to be 0. Therefore, it was interpreted that the correlation matrix was not equal to the identity matrix. According to the results of Bartlett's test of sphericity, the data set was found to be adequate for factor analysis [34]. The linear plot was interpreted to find the number of factors under which the geochemical data were grouped (Fig. 6) [15].

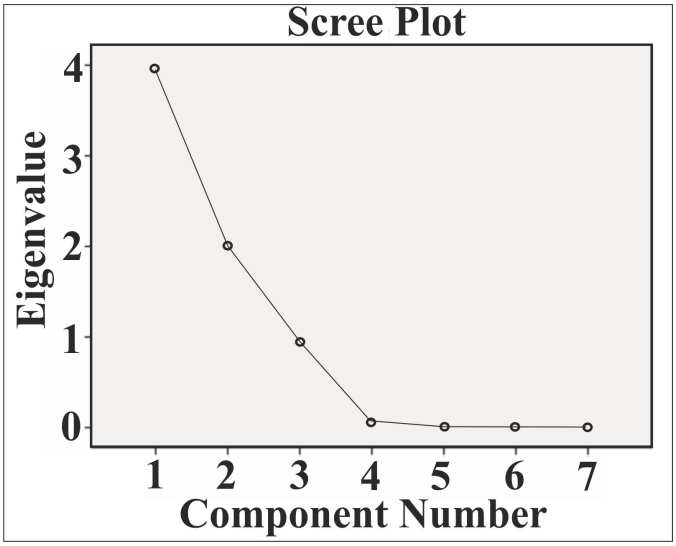


FIGURE 6. Scree plot of the geochemical data.

The scree plot showed that the slope of the plot began to disappear between the points of 2 and 3. Therefore, geochemical data were expected to

be grouped under 2-3 factors. The analysis of the total variance explained revealed the number of factors under which the data were grouped (Table 9).

TABLE 9. Determination of the number of factors based on eigenvalue statistics of dolomites.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	**% of Variance**	Cumulative %	Total	% of Variance	**Cumulative %**
1	3.95	**56.51**	56.51	3.95	56.51	**56.51**
2	2.009	**28.70**	85.21	2	28.70	**85.21**
3	0.954	13.62	98.84			
4	0.061	0.87	99.71			
5	0.012	0.17	99.88			
6	0.007	0.09	99.97			
7	0.001	0.02	100			

Extraction Method: Principal Component Analysis.

Considering the eigenvalues table, the geochemical data were summarized using 2 factors that had a value greater than 1. It was found that the first factor explained 56.51% of the geochemical data while the second factor explained 85.21% of the geochemical data. After determining the number of factors, the principal component matrix analysis was performed on the geochemical data [4]. The final result of the factor analysis was found using the Principal Component Matrix. Thus, the geochemical contents that explained the factors that are considered to be statistically significant were found (Table 10).

TABLE 10. Component matrix table of the geochemical data.

Component Matrix$_a$

	Component	
	1	**2**
MgO	-0.256	0.878
Al_2O_3	0.989	0.045
SiO_2	0.982	0.134
CaO	0.225	-0.971
Fe_2O_3	0.944	0.302
Sr	0.984	0.063
Zr	0.191	-0.424
% of variance explained	56.51	28.70

Extraction Method: Principal Component Analysis, a. 2 components extracted.

It was determined that all components (Al_2O_3, SiO_2 , CaO, Fe_2O_3, Sr, Zr) except for MgO constituted the first factor in the geochemical data.

Their total variance was found to be 56.51%. The component constituting the second factor was found to be MgO, and its total variance was found to be 28.70%. It was interpreted that MgO differed from other geochemical components analyzed and behaved separately. Also, the Principal Component Matrix plot confirmed that MgO constituted the second factor (Fig. 7).

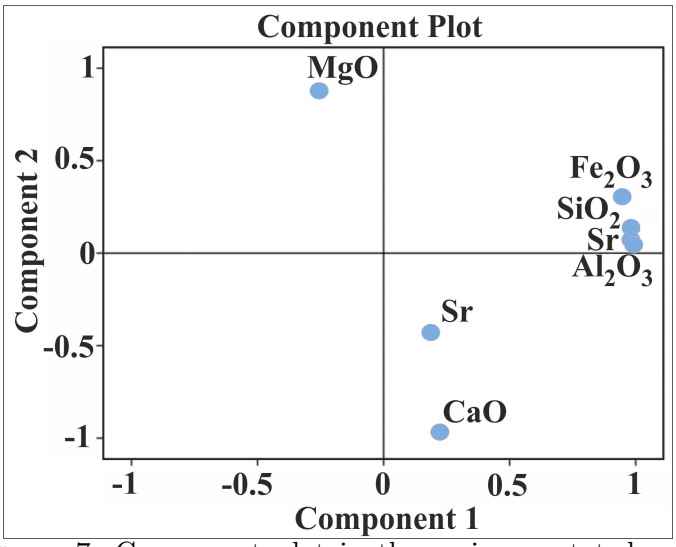


FIGURE 7. Component plot in the varimax-rotated space: Component 1 (56.51%) and Component 2 (28.70%).

The rotated factor matrix plot clearly revealed that the geochemical data of MgO differed from other compounds in the dolomite.

3.2.5. *Cluster Analysis (CA).* In the present study, two different classifications were made for the dolomite samples. In the first classification, the dolomite samples were grouped based on their geochemical features (Fig. 8). On the other hand, the geochemical data of the dolomite samples were subjected to hierarchical clustering analysis as a second classification method (Fig. 9) [39].

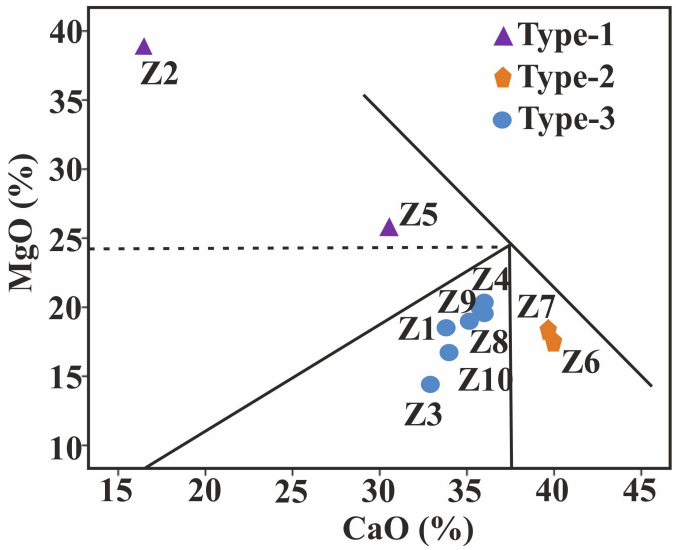


FIGURE 8. The cross-plot of MgO values versus CaO values.

The calcite and aragonite minerals are thought to undergo metasomatism and form dolomite [31], [8]. Therefore, analyzing the behaviors of MgO and CaO in dolomite samples is important in terms of the degree and classification of the metasomatism [8]. If the value is positive, the samples are interpreted to have a sedimentary rock genesis. On the other hand, if the value is negative, the samples are interpreted to have a metasomatic or crystallization-based genesis [54], [8]. Considering (Fig. 8), it is seen that the MgO-CaO distribution in the Type-1 dolomites has a positive correlation. Although Type-1 dolomites are syngenetic, they have been formed in association with sedimentary rocks [8]. Type-2 dolomites show high CaO concentrations and low MgO concentrations. These values indicate that dolomitization is not complete [8]. On the other hand, Type-3 dolomites have low CaO concentrations and higher MgO concentrations. This type is observed to have a negative linear correlation with other types. The Dolomites of this type are thought to have completed their formation phase [8].

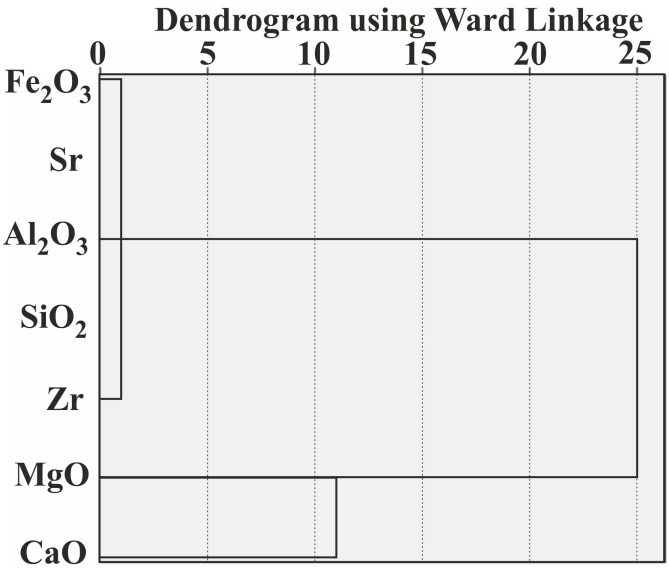


FIGURE 9. Hierarchical clustering of the geochemical data.

According to the hierarchical clustering analysis, considering their geochemical data, the dolomite samples were grouped under two clusters that could be explained statistically. The geochemical compounds that constitute the first cluster were found to be Fe_2O_3, Sr, Al_2O_3, SiO_2, and Zr. The geochemical compounds that constitute the second cluster were found to be MgO and CaO. As the samples collected from the region were observed to be classified under three geochemical types, the distributions of the major and trace elemental compounds in the determined types were examined. Therefore, heat map distributions were generated (Fig. 10). Heat map distributions were generated using two nominal variables. The heat map distributions facilitate understanding and interpreting the distributions of nominal variables with numerical variables. Thus, the codes of the dolomite samples and dolomite types (Type-1, Type-2, Type-3) extracted according to the MgO-CaO plot were selected as two nominal variables (Fig. 8).

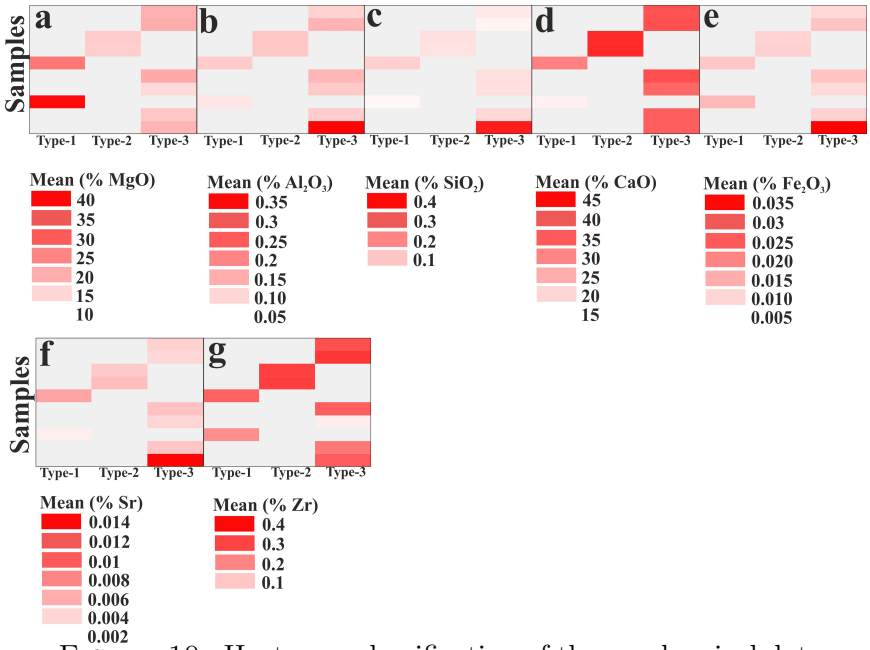


FIGURE 10. Heat map classification of the geochemical data a) MgO b) Al_2O_3 c) SiO_2 d) CaO e) Fe_2O_3 f) Sr and g) Zr.

The heat map distributions were generated separately for each chemical component. Type-1 dolomites (medium crystalline dolomite) (Z2 and Z5) were found to have the highest MgO concentration in the region, while they had lower concentrations of Al_2O_3, SiO_2, CaO, Fe_2O_3, and Sr. Type-2 dolomites (micrite crystalline dolomite) (Z6, Z7) were found to have the highest CaO and Zr concentrations in the region while they had lower concentrations of MgO, Al_2O_3, SiO_2, Fe_2O_3, and Sr. On the other hand, Type-3 dolomites (dolarenite) (Z1, Z3, Z4, Z8, Z9, Z10) were found to have the highest concentrations of Al_2O_3, SiO_2, CaO, Fe_2O_3, Sr, and Zr in the region, whereas they had lower concentrations of MgO. The results of heat map distributions proved that the dolomite formation in the region developed based on various genesis and processes. It is thought that Type-1 dolomites have completed their formation process while Type-2 and Type-3 dolomites have gone through the dolomite formation process. Therefore, it was considered that the dolomite samples that were extracted from the region and taken into the operation phase may have various qualities.

3.3. **Mineralogical and petrographic features.** The Alizarin red test, as well as XRD and thin cross-section analyses, were performed on the samples collected from the field. The results of these analyses provided information about the mineralogical and petrographic properties of dolomites. The Alizarin red test was conducted to achieve dolomite-calcite separation. Since no color change was detected during the Alizarin red test, it was confirmed

that the samples were dolomite [11]. Moreover, the mineralogical properties of the samples were analyzed by XRD analysis (Fig. 11-a, b). Single-nicol and double-nicol images of the thin cross-sections of the dolomite samples were taken (Fig. 12-a, b).

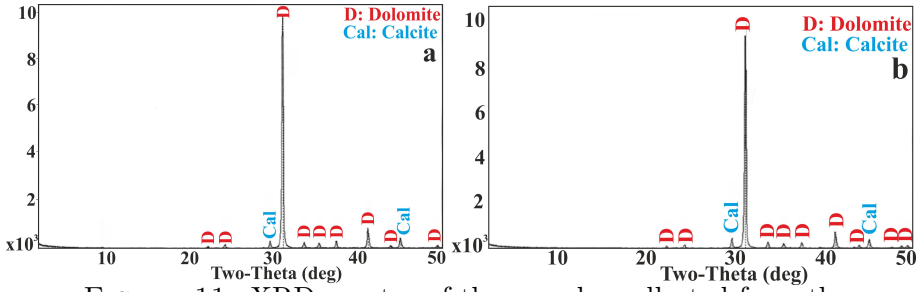


FIGURE 11. XRD spectra of the samples collected from the field [11].

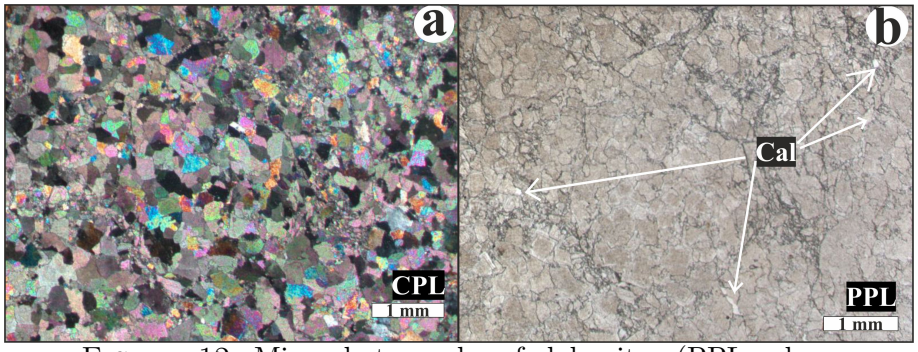


FIGURE 12. Microphotographs of dolomites (PPL: plane-polarized light, CPL: crossed-polarized light, Cal=Calcit) [11].

According to the XRD peaks, 90% of the mineralogical content of the samples was found to consist of dolomite mineral while 10% of that was found to consist of calcite mineral (Fig. 11-a, b). Cracks were observed in the double-nicol images of the samples that were recrystallized (Fig. 12-a). On the other hand, single-nicol images showed calcite minerals with clear boundaries [11] (Fig. 12-b).

4. CONCLUSION

According to the mineralogical and petrographic examinations carried out in the study, 90% of the mineralogical content of the samples consists of dolomite mineral while 10% of the mineralogical content consists of calcite mineral. According to the thin cross-section images, dolomite was usually

found to be the dominant mineral in the samples with lower contents of recrystallized calcite mineral. The Alizarin red tests also confirmed that dolomite was the most abundant mineral content in the samples. The mean CaO and MgO concentrations of dolomite samples were found to be CaO (33.43 ± 2.11) > MgO (20.56 ± 2.29) in the descending order. As two descriptive statistics, kurtosis and skewness describe the shape of the distribution. The skewness of the geochemical data were found as MgO (-3 < 2.19 < 3), Al_2O_3 (-3 < 2.87 < 3), SiO_2 (-3 < 2.95 < 3), CaO (-3 < -1.94 < 3) ¡ Sr (-3 < 2.66 < 3), Zr (-3 < -1.87 < 3). The skewness of Fe_2O_3 major geochemical content was found to be 3.01, which slightly exceeds the range between -3 and 3. The arithmetic mean, mode, and median values of the geochemical contents of MgO, Al_2O_3, SiO_2, CaO, Fe_2O_3, Sr, and Zr were calculated as (20.56, 18.95, 14.4), (0.13, 0.11, 0.07), (0.07, 0.04, 0.01), (33.43, 34.6, 16,6), (0.01, 0.01, 0.01), (0.005, 0.004, 0.002), (0.23, 0.25, 0.02), respectively. The arithmetic means of the geochemical contents of MgO, Al_2O_3, SiO_2, and Sr were found to be higher than their mode and median values. The distribution was found to be right-skewed, i.e., it tends to have negative low values. The mode values of CaO and Zr were found to be higher than their arithmetic mean and median values. The distribution was found to be left-skewed, i.e. it tends to have positive high values. The arithmetic means, mode, and median values of Fe_2O_3 were found to be equal, and it had a symmetrical distribution curve. The skewness and kurtosis values calculated for the geochemical data confirmed the skewness values interpreted by box-plot analysis (Fig. 3) and the kurtosis values interpreted by the histogram analysis (Fig. 4). The normality of the distribution of the geochemical dataset was tested using the Shapiro-Wilk test. The alternative hypothesis of Ha was accepted as the p-values were <0.005. Since the dataset did not provide the normality assumption, Spearman's rank-difference correlation method was preferred. It was determined that the major geochemical content of MgO had a negative correlation with all other geochemical compounds except for Fe_2O_3. The correlation analysis revealed that the highest elemental relationship in the region was between SiO_2-Sr (0.818^{**}). This elemental relationship was tested by regression analysis to explain it statistically. The mathematical model of the regression analysis, which was found to have a p-value 0<0.5 is as follows: (%) SiO_2 = -0.1 + 31.92 * (%) Sr + ϵ (R^2 = 0.97, P-value =0) (Fig. 5). The cumulative value of the factor analysis, which resulted in two factors, was found to be 85.21%. According to the principal component analysis, the components that constitute the first factor were found to be Al_2O_3, SiO_2, CaO, Fe_2O_3, Sr, and Zr, except for MgO. The second factor consisted of only MgO (Fig. 7). According to the geochemical classification, the samples were divided into three types. Type-1 (Z2 and Z5) was medium crystalline dolomite, Type-2 (Z6 and Z7) was micrite fine crystalline dolomite, Type-3 (Z1, Z3, Z4, Z8, Z9, Z10) dolarenite (Fig. 8). The elemental distribution maps (Fig. 2) created using the coordinates of the dolomite samples were observed to be consistent with the

heat maps created using the types and sample coding (Fig. 10). Accordingly, Type-1 dolomites were found to have high and similar concentrations of MgO; Type-2 dolomites were found to have high and similar concentrations of CaO and Zr; Type-3 dolomites were found to have high and similar concentrations of Al_2O_3, SiO_2, Fe_2O_3, and Sr. The MgO and CaO contents of the dolomite samples were compared with those of other countries. The MgO value was found to be higher than those of India, Northern Italy, and Malaysia but lower than those of Southern Missouri and Egypt, and similar to those of Turkey (Mersin), and China. Considering the CaO value, it was found to be higher than those of India, Northern Italy, and Southern Apennines, lower than those of Southern Missouri, Malaysia, and Egypt, and similar to those of Turkey (Mersin) and China. The multivariate and spatial statistical methods, which were included in the applied mathematics, were performed on geochemical data. The results of these analyses revealed that the dolomites extracted from the study area had different genesis and types. Determining these differences is essential in the operation processes of the dolomites, which are important industrial raw materials.

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Acknowledgments

This paper is a part of the M.Sc. thesis of Z. INCE, the first author.

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