Mineralogy and Provenance of Titanium-Vanadium Bearing Iron Sand Deposits from Purworejo-Kebumen, and Cilacap, Central Java

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Abstract. This research aimed to find out the provenance, paleo weathering, tectonic environment, sediment maturity, and economic value of beach sand deposits in two study areas. The study areas were located on south coast of Purworejo-Kebumen and Cilacap, respectively. Ten representative samples were collected by hand auger and dried to reduce their water content, manually separating the magnetite concentrate using a 300-gauss magnet. The mineral composition and fraction were observed using a binocular microscope. Major oxide and trace elements concentrations were measured using the X-ray fluorescence and inductively coupled plasma mass spectrometry methods, respectively. The mineral assemblage consisted of pyroxene, amphibole, heavy minerals (hematite, ilmenite, and magnetite) and the light minerals found were quartz, plagioclase, and lithic fragments. The geochemical plot showed that all samples could be classified as greywacke, derived from mafic igneous provenance and were tectonically formed within an arc setting. The Chemical Index of Alteration showed an intensity of weathering as expected from tropical climates with weak weathering and the sediments are close to their source rock location. Fe_2O_3 had a positive correlation with TiO_2 and V_2O_5; the iron sand from both areas has potential to be extracted, with iron, titanium, and vanadium as main commodities.

Keywords: *chemical index of alteration; iron; iron sand; titanium; vanadium.*

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1 Introduction

Iron sand deposits are deposits containing iron particles and are found along coast lines [1]. Iron sand deposits are accumulations of resistant heavy mineral particles of high specific gravity deposited by the action of waves, currents, and winds [2]. Heavy minerals are usually defined as those with a specific gravity >2.6 g cm^{-3} and the majority of valuable heavy minerals occur as oxides and include economically important minerals rich in titanium, zirconium, and rare earths [3]. Iron sand is the result of the erosion of alluvium deposits on land. It is known as a terrigenous sediment and is widely used as a mixture in the cement industry.

As terrigenous sediment, major and trace elements of these deposits have been used to understand their provenance [4-6]. The mineral phase contains rare earth elements, so the industrial importance and economic value of iron sand varies [7,8].

Regions in the island of Java that have iron sand deposits are located on the southern shores, spanning the provinces of East Java, Yogyakarta, Central Java, and West Java [9]. In Indonesia, iron sand is known as a source of TiO_2 in the form of ilmenite or titanomagnetite [10].

This study was conducted on the southern coast of Purworejo-Kebumen and Cilacap, Central Java, Indonesia (Figure 1). These three areas are among the areas that have considerable iron sand potential in Indonesia. The aim of this research was to identify the tectonic provenance, weathering index, and economic importance of the deposits in the study area.

2 Regional Geology

In general, iron deposits on the south coast of Java Island, and specifically those in the research area, are closely related to the geological setting of the Java Island region. During the late Cretaceous period to the early Tertiary, there was subduction between the Australian Plate and the Sunda Microplate, which trended northeast-southwest. This subduction produces a west-east trending pattern along West Java, then turns northeast around Karang Sambung towards Mt. Meratus (South Kalimantan).

The Lok Ulo Complex, which is located in the north of the research area, is a representation of sediment in the forearc basin deposited during that tectonic period. During the Oligocene-Early Miocene period there was a slowdown in the movement of the Australian Plate [11]. This caused the plate subduction angle to become higher. Then, in the Mid-late Miocene, magmatic activity occurred along the island of Java [12], which produced various volcanic products. The results of chemical analysis of the ash from the eruption of Mt. Merapi in Jogjakarta in 1969 contained 5.27% to 6.92% Fe_2O_3. Lava rock from the 1940 Merapi eruption contains 10.44% Fe_2O_3 and Merapi ash from the 1972 eruption contains 6.59% Fe_2O_3 and 3.02% FeO [13].

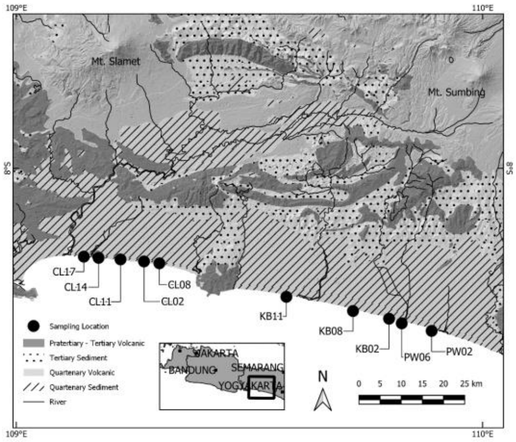

Figure 1 Research area and sample location.

The lithology of the sampling area (Figure 1) is dominated by Quaternary deposits in the form of fine-medium and very loose sand [14]. Meanwhile, in the northern part of the research area there is a distribution of Tertiary sedimentary rocks, which include the Halang Formation, the Waturanda Formation, the Penosogan Formation, the Totogan Formation and the Peniron Formation. In addition, there are the Gabon Formation, the Kalipucang Formation and several andesite intrusions that are scattered in the south-western part of Kebumen near the border with Cilacap Regency. Ultramafic rocks and the Lok Ulo Complex are exposed in the northern region of Kebumen. After Tertiary-aged rocks were formed, several Quarter-aged rocks were deposited unconformably above them, namely Ligung Formation, Slamet Volcano, and Sumbing Volcano material [15]. This lithology can be grouped into four rock units based on their age and material compositions. The four groups of rock units include pre-Tertiary volcanic sediment, Tertiary sediment, Quaternary volcanic sediment, and Quaternary sediment. The Pretertiary-Tertiary volcanic rock group comprises rocks whose composition is dominated by volcanic material that is Limestone-Tertiary in age. The oldest rocks of this group are mafic and ultramafic rocks in the form of Cretaceous gabbro, serpentinite and basalt, which include the Gabon Formation, the Halang Formation of Breccia Members, and the Peniron Formation. Some Tertiary andesitic intrusions are also included in this group.

The Tertiary sedimentary group is dominated by rocks that have undergone further sedimentation processes and are characterized by sandstone, claystone and carbonate rocks. One of the rock units included in this group is the Lok Ulo Complex with a basalt mass of black shale and with fragments in the form of gabbro, andesite, serpentinite, basalt, sandstone, schist, and chert [14]. In addition, several formations are also included in this group, namely the Halang Formation, the Totogan Formation, the Penosogan Formation, and the Kalipucang Formation.

3 Material and Methods

Ten representative samples were collected from the shoreline along the research area (Figure 1). The samples were collected from hand auger drilling at approximately 5 kg for each sample, with the depth varying from 1 to 4 m (Figure 2).

Figure 2 Sampling of iron sand using hand auger.

The samples were dried to reduce their water content, manually separating the magnetite concentrate using a 300-gauss magnet. They were then investigated using a binocular microscope at the Laboratory of Center for Mineral Coal and Geothermal Resources, Bandung to investigate their mineral composition and fraction. Major oxide and trace element concentrations were measured using (X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS), respectively. All of the laboratory work was conducted at the Laboratory of the Center for Mineral Coal and Geothermal Resources, Bandung, Indonesia.

4 Results

4.1 Grain Size Characterization

The grain size distribution was calculated using graphical statistic equations [16]. Mzφ (1.39 to 1.98) and δφ had a negative skewed, near symmetrical, and strongly positive skewed correlation, where all grain sizes were the same size, with δφ values ranging from 0.60 to 0.82, falling in the moderately sorted category. On average, the sand samples were very fine skewed (-0.05 to 0.41) with very platykurtic distributions and a kurtosis value of 0.48 to 0.64, except for example CL08 from Cilacap, which included platykurtic with a skewness value of 0.36 and a kurtosis value of 0.73 (Table 1).

Table 1 Textural characteristics of iron sands in Cilacap, Purworejo-Kebumen, Central Java.

Sample code	Mean Size	Std. Dev	Skewness	Kurtosis	Mean Class	Std. Dev. Class	Skewness Class	Kurtosis Class
CL02	1.98	0.7	0.35	0.59	Fine Sand	Moderately Sorted	Strongly positive skewed	Very Platykurtic
CL08	1.85	0.6	0.36	0.73	Fine Sand	Moderately Sorted	Strongly positive skewed	Platykurtic
CL11	1.93	0.66	0.41	0.64	Fine Sand	Moderately Sorted	Strongly positive skewed	Very Platykurtic
CL14	1.91	0.7	0.37	0.59	Fine Sand	Moderately Sorted	Strongly positive skewed	Very Platykurtic
CL17	1.62	0.82	0.02	0.63	Fine Sand	Moderately Sorted	Near symmetrical	Very Platykurtic
PW02	1.39	0.74	-0.2	0.48	Fine Sand	Moderately Sorted	Negative skewed	Very Platykurtic
PW06	1.63	0.66	-0.05	0.57	Fine Sand	Moderately Sorted	Near symmetrical	Very Platykurtic
KB02	1.88	0.67	0.36	0.58	Fine Sand	Moderately Sorted	Strongly positive skewed	Very Platykurtic
KB08	1.63	0.6	-0.08	0.54	Fine Sand	Moderately Sorted	Near symmetrical	Very Platykurtic
KB11	1.55	0.72	0.03	0.51	Fine Sand	Moderately Sorted	Near symmetrical	Very Platykurtic

4.2 Mineralogy

The mineral assemblage from both research areas was made up of magnetite, ilmenite, hematite, pyroxene, quartz, amphibole, plagioclase, quartz, and a small amount of rock fragments. Fossils were found in small quantities in the sand samples from Cilacap, while in the samples from Purworejo-Kebumen they were rare. Meanwhile, garnet, muscovite, and zircon were found in trace amounts. These minerals could be classified into light and heavy minerals based on their density. Heavy minerals are usually defined as those with a specific gravity >2.6 g cm^{-3} [3].

The laboratory observation results showed that the iron sand in the research area contains minerals such as pyroxene, amphibole, hematite, ilmenite, plagioclase, quartz, and small amounts of lithic/rock fragments, as well as rare minerals such as garnet, muscovite, zircon and mica. The samples consisted of pyroxene (55.32 to 77.48 wt%), amphibole (1.97 to 6.13 wt%), and heavy minerals such as hematite (0.34 to 2.29 wt%), ilmenite (2.59 to 9.69 wt%), and magnetite (1.98 to 17.40 wt%). The light minerals found were quartz (0.01 to 6.2 wt%) and plagioclase (1.48 to 21.47 wt%). Lithic fragments occurred as minor materials, found as trace to 4.81 wt% (Table 2).

Table 2 Mineral composition percentages.

Minerals	Percentage Weight									
	CL02	CL08	CL011	CL014	CL017	PW02	PW06	KB02	KB08	KB11
Magnetite	5.242	1.98	8.98	17.40	9.30	5.99	17.23	11.38	3.05	2.74
Ilmenite	6.144	9.69	6.08	2.90	2.59	4.50	2.86	2.80	2.97	2.96
Hematite	2.288	1.94	0.98	1.10	0.98	1.00	1.00	0.34	1.00	1.01
Pyroxene	74.660	71.32	77.48	72.17	76.59	63.00	65.90	55.32	75.93	58.29
Quartz	6.204	1.10	1.59	0.01	0.71	0.98	0.07	0.49	1.02	4.32
Amphibole	2.560	1.97	2.42	2.02	3.53	6.52	6.13	4.73	4.92	4.41
Rock fragments	0.023	1.52	0.01	2.92	4.81	3.51	2.04	3.47	1.30	0.77
Fossil	0.007	0.01	Trace	0.01	0.01	Trace	-	Trace	Trace	0.02
Garnet	-	-	-	-	-	trace	trace	-	-	
Plagioclase	3.176	10.48	2.47	1.47	1.48	14.50	4.76	21.47	9.81	25.47
Muscovit	trace	trace	-	-	-	-	-	-	-	-
Zircon	-	-	-	-	-	-	-	Trace	-	-
Mica	-	-	-	-	-	-	-	-	-	Trace
Total	100	100.01	100.01	100	99.99	100	99.99	100	100	99.99

4.2.1 Light Minerals

Quartz is colorless with the highest scale of hardness scale (7 Mohs). It also has a vitreous luster. The quartz found in the samples from the research area was present in small amounts (trace to 6% wt%), while plagioclase was present in larger amounts (1.47 to 25.47% wt%), making it the main light and nonmagnetic mineral [17]. Quartz is the hardest mineral based on the Mohs hardness scale; it is colorless, diamagnetic, has a glassy luster, and is present as gangue in iron sand deposits. Light minerals found were quartz (0.01 to 6.204 wt%) and plagioclase (1.48 to 21.47 wt%). Lithic fragments occurred as minor materials, found as trace to 4.81 wt%. Plagioclase has a dull-white color with vitreous luster. Plagioclase tended to be less present in Cilacap than in Purworejo-Kebumen. The lithic/rock fragments generally had a dark color (Table 2 and Figure 3).

4.2.2 Heavy Minerals

Magnetite has a black to brownish black color, forming a chain near a magnetic force. The brownish color indicates oxidation [18]. Ilmenite has a black color, rounded to subrounded grains, and a metallic luster. Hematite is a paramagnetic mineral with a reddish black color and is generally found as trace with the highest percentage being 2.29% (CL02). It can be formed as replacement of magnetite’s oxidation. Magnetite, ilmenite, and hematite belong to the group of heavy minerals. They were present in all iron sand samples analyzed from the research area. It seems that these three types of heavy minerals originated from the weathering of the same rocks from the northern part of the research area, which was transported via rivers towards the south.

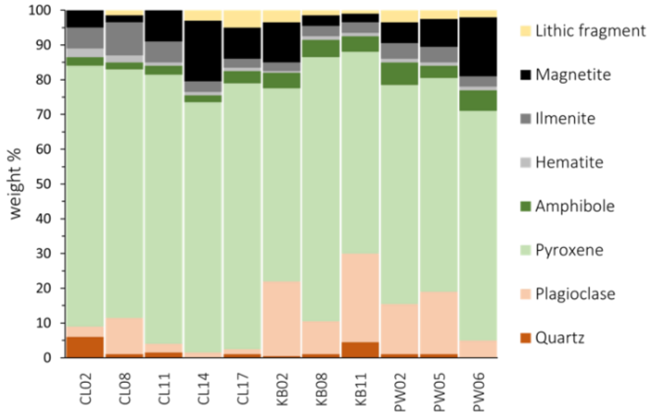

Figure 3 Mineral percentages of all locations that show domination of pyroxenes.

Pyroxenes have an angular to sub-angular prismatic shape with a greenish black color and have vitreous to resinous luster. Amphiboles are prismatic with angular to subangular outlines, a vitreous luster, and a black color. Pyroxenes and amphiboles are non-magnetite minerals, formed in igneous rock and volcanic rock.

The heavy mineral content (magnetite, ilmenite and hematite) in the Cilacap coastal area (CL11, CL14 and CL17) and from Purworejo (PW06) was higher than in the samples of iron sand from the Kebumen coastal area. The high heavy mineral content in Cilacap probably comes from the Slamet volcanic deposits, while the high heavy mineral content in Purworejo-Kebumen is closer to intermediate igneous rocks.

4.3 Geochemistry

4.3.1 Major Elements

The XRF analysis result of the samples is summarized in Table 3. The plot of (K_2O/Na_2O) log and (SiO_2/Al_2O_3) log [19] shows all samples classified as greywacke (Figure 4). The samples normalized by Upper Continental Crust

(UCC) showed that the major elements from PW-KB and CL displayed similar patterns, except P_2O_5, where the PW-KB samples exhibited enrichment relative to CL (Figure 5).

Table 3 Major elements compositions of samples from XRF analysis.

Major Elements and Oxides (%)	Sample Code									
	PW02	**PW06**	**KB02**	**KB08**	**KB11**	**CL02**	**CL08**	**CL011**	**CL14**	**CL17**
SiO_2	50.020	43.310	48.100	48.970	52.520	45.680	47.100	44.330	44.140	42.860
Al_2O_3	20.100	11.630	19.810	19.520	21.270	18.270	19.890	14.280	13.510	10.810
Fe_2O_3	9.010	16.420	10.910	8.700	6.350	12.650	9.090	15.590	17.740	19.980
CaO	9.300	12.440	10.520	10.230	8.120	7.850	6.100	9.960	8.980	10.180
MgO	4.070	9.290	4.660	5.230	4.060	6.510	6.530	8.940	8.750	10.290
Na_2O	3.440	2.160	3.170	3.390	3.540	2.500	2.520	2.200	2.240	1.810
TiO_2	0.916	1.630	1.020	0.817	0.678	1.250	0.742	1.570	1.840	2.050
K_2O	1.400	0.733	1.260	1.280	1.250	0.858	1.070	0.619	0.580	0.466
Cl	0.197	0.188	0.027	0.186	0.178	0.152	0.204	0.223	0.183	0.154
MnO	0.248	0.432	0.286	0.261	0.180	0.279	0.251	0.333	0.325	0.352
P_2O_5	0.357	0.576	0.440	0.352	0.227	0.160	0.153	0.172	0.165	0.177
SO_3	0.040	0.067	0.020	0.042	0.044	0.080	0.087	0.076	0.059	0.045
V_2O_5	0.049	0.094	0.053	0.042	0.033	0.073	0.036	0.094	0.119	0.129
SrO	0.043	0.012	0.041	0.041	0.050	0.021	0.025	0.009	0.006	-
Cr_2O_3	0.004	0.008	0.005	0.005	0.013	0.018	0.011	0.038	0.040	0.062
ZnO	0.010	0.016	0.010	0.010	0.017	0.013	0.010	0.015	0.016	0.018
BaO	0.037	-	0.029	0.032	0.036	0.029	0.021	-	-	-

The plot between the major element oxides and the SiO_2, Al_2O_3, and Fe_2O_3 content of all samples indicates variable correlations. Positive correlations were seen between SiO_2 vs Al_2O_3, Na_2O, K_2O; Al_2O_3 vs Na_2O and K_2O; Fe_2O_3 vs TiO_2, V_2O_5, P_2O_5. The samples from both areas showed similar patterns. Furthermore, the samples from Purworejo-Kebumen had a high positive correlation. Positive correlations were seen between SiO_2 vs Al_2O_3, Na_2O, K_2O; Al_2O_3 vs Na_2O and K_2O; Fe_2O_3 vs TiO_2, V_2O_5, P_2O_5, while the Cilacap samples had lower positive correlation values (Figure 6).

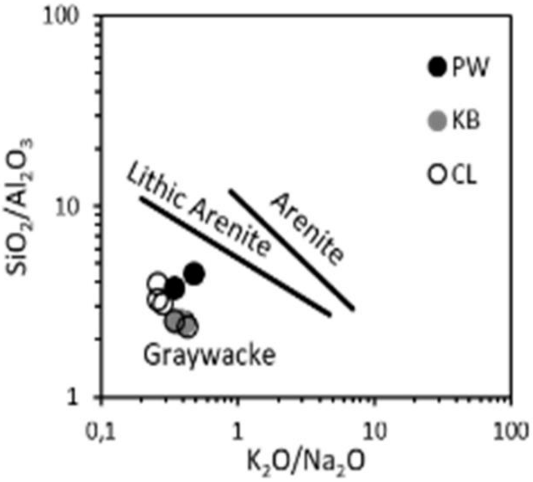

Figure 4 SiO_2/Al_2O_3 vs K_2O/Na_2O shows all of the samples classified as graywacke [19].

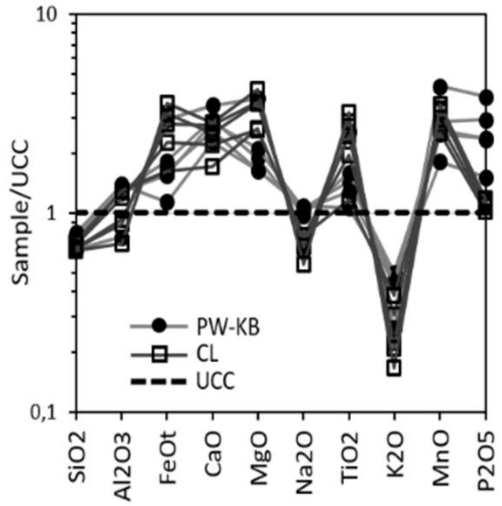

Figure 5 Spider diagram of the iron sand deposits' major elements compared to Upper Continental Crust [19].

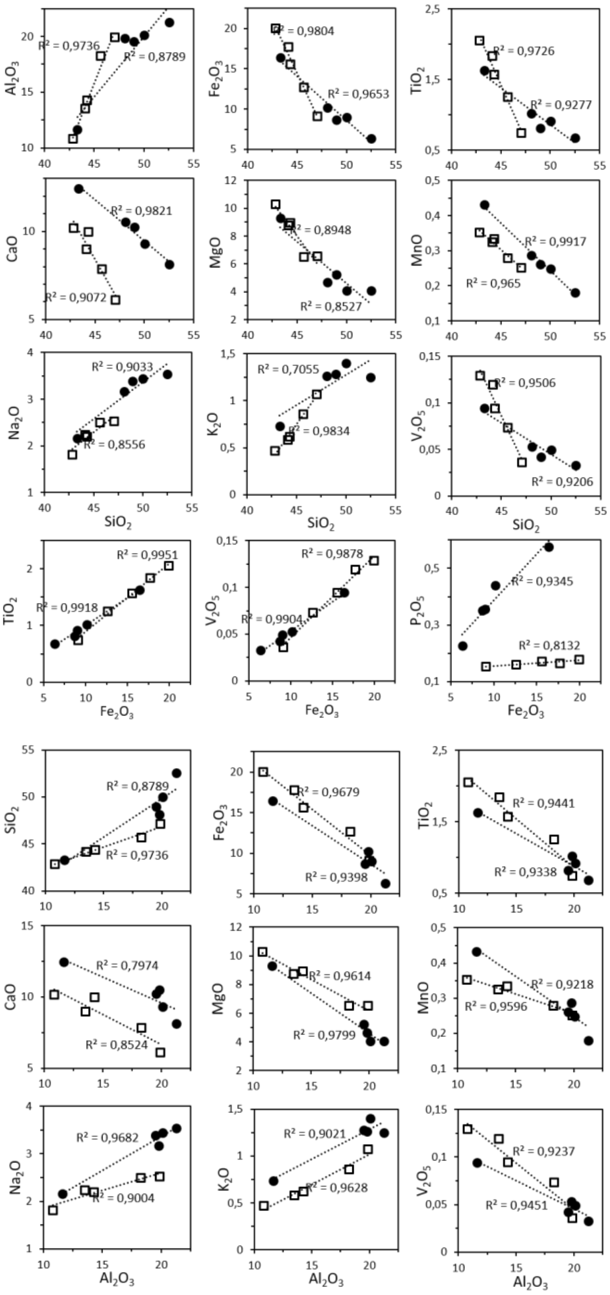

Figure 6 Harker diagram of SiO_2, Al_2O_3, and Fe_2O_3 vs major elements (R^2 is the gradient of the line equation in mathematics).

4.3.2 Trace Elements

The elements Cu, Co, Ni, Cr, Sr, Zr, and Ba from all samples are presented in Table 4. Transitional elements such as Cu, Co, Ni, and Cr were observed to have higher availability in samples from Cilacap beach. Meanwhile, Sr and Ba, which have light lithophile ions (LILE), were more abundant in samples from Purworejo-Kebumen. These elements are generally found in alkaline feldspar rock and are preserved during chemical weathering processes.

Table 4 Trace element compositions of samples from Purworejo-Kebumen and Cilacap (XRF analysis).

No	Samples Code	Cu	Co	Ni	Cr (ppm)	Sr	Zr	Ba
1	PW02	22	61	12	24	339	55	253
2	PW06	15	61	15	25	148	34	88
3	KB02	21	57	13	19	267	46	186
4	KB08	21	50	11	33	280	46	200
5	KB11	22	42	17	64	313	39	230
6	CL02	34	79	46	127	224	47	116
7	CL08	50	59	97	283	265	54	166
8	CL11	25	97	64	179	141	38	62
9	CL14	27	92	54	175	155	41	84
10	CL17	21	90	57	186	127	35	71

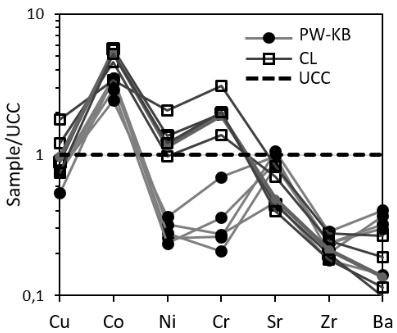

Figure 7 Multi-element diagram for trace element concentrations normalized towards the Upper Continental Crust [19].

These elements are generally found in alkali feldspar rocks and preserved during chemical weathering. The Zr from both areas has similar values. These trace element data were normalized using Upper Continent Crust values (Figure 7). The patterns showed that the Cu, Ni, and Cr from Cilacap were enriched but depleted in Purworejo-Kebumen; the Co from both areas was enriched; the Sr, Zr, and Ba from all regions were depleted. Based on regional geology, the Cilacap research area has rivers that originate on Mt. Slamet and Mt. Sumbing, the latter of which is occupied by Tertiary volcanic rock, known as the Old Andesite Formation. The Old Andesite Formation also carriers hydrothermal mineralization. Meanwhile, upstream in the Purworejo-Kebumen area, it covers Tertiary sedimentary rock hills.

5 Discussion

Geochemical studies of clastic sediments are currently very appropriate for interpreting the origin of sediments [19-23] and for determining the intensity of paleo weathering [24-26] as well as the tectonic structure of the sedimentary basin where it was deposited [27,28]. Geochemical data on iron sand deposits can explain the origin of rocks on land [29], which means their formation occurred in a terrestrial environment (terrigenous sediments).

5.1 Provenance

All samples from the three beaches were classified into mafic igneous provenance [30], DF1 = (log (K_2O/Na_2O) and DF2 = log (SiO_2/Al_2O_3) (Figure 8). This result was supported by Amajor’s diagram [31], where the samples from Purworejo were interpreted to come from basalt and rhyolite/granite (Figure 9).

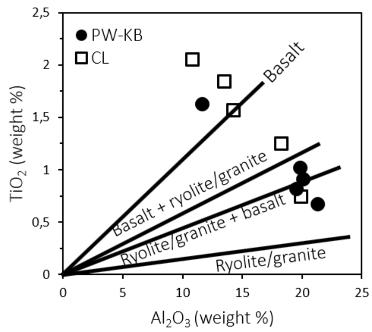

Figure 8 Iron sand deposits provenance classified into mafic-igneous based [30].

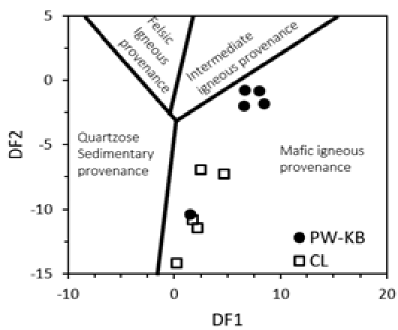

Figure 9 The samples had various origins [31].

Iron sand deposits mainly result from the erosion of volcanic basaltic and andesitic rocks, for example, the heavy mineral-rich iron sands of the Waitakere coast, Auckland, New Zealand originate from Taupo Volcanic Zone rhyolitic volcanic and andesitic volcanic rocks [32].

These results indicate that the iron sand deposits in this area originate from the Old Andesite Formation process of forming magnetite and ilmenite minerals in the interior of Cilacap [33]. These results also show that the iron sand in Kebumen has the most acidic provenance. Besides that, all samples had high potassium content (Figure 10).

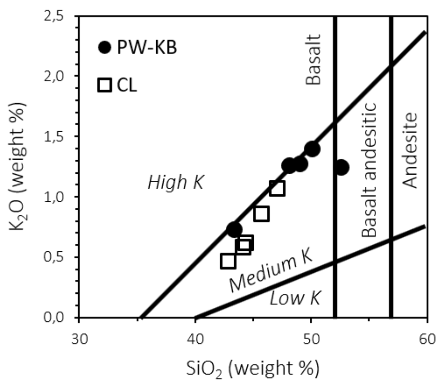

Figure 10 Comparison of K_2O and SiO_2 showed that the majority of samples were from high K basalt [31].

The iron sand deposits in Kebumen are expected to originate from basalt + ryolite/granite and ryolite/granite + basalt, while the deposit in Cilacap has provenance from basalt and ryolite/granite + basalt [31].

5.2 Index of Weathering

One of the processes that sedimentary material goes through before being deposited is the weathering of the original rock. There are several values that can be calculated to determine the level of weathering of sediment, including the Chemical Index of Alteration (CIA). In CIA calculations, the ratio between Al_2O_3 and the oxide compounds Al_2O_3, Na_2O, CaO and K_2O is used with the formula [34]:

$$\mathrm{CIA} = \frac{\mathrm{Al_2O_3}}{\mathrm{Al_2O_3+Na_2O+CaO^*+K_2O}} \qquad (1)$$

The CIA results in the research area, using XRF data on the major elements and oxide content of the iron sand deposits (Table 3) showed an amount greater than 50% (Table 5), meaning an intensity of weathering as expected from a tropical climate region like Indonesia.

Table 5 Chemical Index of Alteration (CIA) calculation results.

Samples Code	PW02	PW06	KB02	KB08	KB11	CL02	CL08	CL11	CL14	CL17
CIA Values	70.82	69.71	72.27	70.78	71.86	75.72	76.50	73.99	72.75	72.57

References [34-36] used a ternary plot of Al_2O_3 – (CaO+Na_2O) – K_2O to deduce weathering trends to determine the relation between mineral composition, source rocks, and weathering paths. Plotting the Al_2O_3 – (CaO+Na_2O) – K_2O (Table 3) of the examined samples in this ternary diagram displayed a weak weathering history with sand beach (Figure 11).

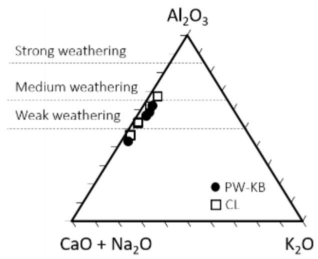

Figure 11 Ternary diagrams of Al_2O_3 – (CaO+Na_2O) – K_2O showing the paleoweathering condition [34].

5.3 Tectonic Setting

Determination of the tectonic setting was done by applying new multi-dimensional diagrams [27] consisting of arc, rift, and collision classification. Based on the value of major elements, the samples from both Purworejo-Kebumen and Cilacap fell within the arc setting (Figure 12).

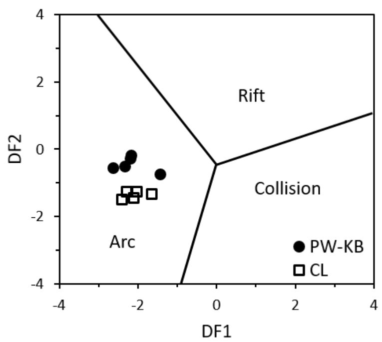

Figure 12 The samples from both Purworejo-Kebumen and Cilacap were produced by an arc setting [27].

5.4 Sediment Maturity

The mineralogical maturity can be determined by understanding the composition of a clastic sedimentary body. A higher maturity is reflected by the predominance of quartz and the absence or scarcity of less resistant minerals [38]. Hydraulic sorting and sediment compositional maturity of sediments can be determined by the ICV (Index of Compositional Variability) formula [39]:

$$ICV = (CaO + K_2O + Na_2O + Fe_2O_3 + MgO + MnO + TiO_2)/Al_2O_3 \quad (2)$$

Fe_2O_3 implies the total iron from all sources. The CaO values also imply total Ca, which is believed to be the main parameter of sediment maturity [40,41]. The higher the degree of weathering, the lower the ICV values. This value would be low with the abundance of clay minerals, indicating intensive weathering, whereas rock forming minerals like pyroxenes, plagioclase, amphiboles, and k-feldspar have high ICV values [39]. Immature sediments of the first cycle have ICV values >1, while compositionally matured sediments that may derive from a region with slow tectonic uplift will have ICV values <1 [39, 21].

All of the ICV values of the samples were >1, suggesting they mostly comprised rock-forming minerals and probably came from a high-relief region located to the north of the research area. This immaturity indicates a lack of travel time, because unstable minerals that may be removed and leaching during the transportation still occurred. Consequently, it also implies that the sediments are located close to their source rock location.

5.5 Economic Importance

Concentrations of magnetite occur in the iron sand deposits along the southern coast of Java Island and have been identified especially in Cilacap [41]. Based on the percentage of Fe_{total} and TiO_2 from raw and concentrated samples, it is known that the samples from Cilacap had a relatively higher percentage of Fe and TiO_2 than the samples from Purworejo-Kebumen (Figure 13).

Fe_2O_3 has a positive correlation with TiO_2 and V_2O_5 in iron sand deposits from these two regions, which have the potential to be extracted with iron, titanium and vanadium as the main commodities (Figure 6).

Iron sand is known as a source of TiO_2 in the form of ilmenite or titanomagnetite. The iron titanium oxide minerals found on the southern coast of Purworejo-Kebumen, and Cilacap can be classified as titanomagnetite [10]. To fulfil this economic potential, further and more detailed research is needed, especially on measurable reserves and resources. When compared with iron sand mining in

Cilacap by PT. Aneka Tambang [33], Antam applies an economic limit of 10% MD (total percentage of magnetic fraction). For this research area, the Cilacap area has better prospects compared to the Purworejo-Kebumen area. Cilacap has Fe_2O_3 levels between 9.09% and 19.98%, while the Kebumen area in one location has Fe_2O_3 levels of 10.19%, and Purworejo 16.42%.

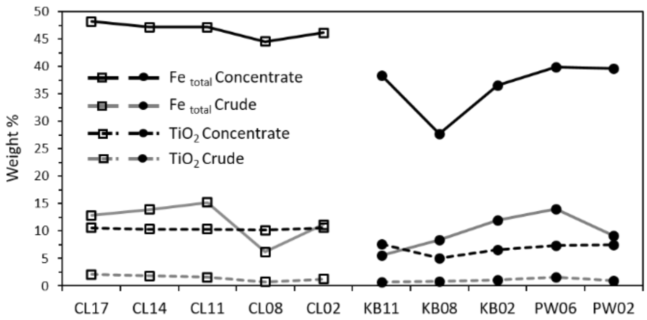

Figure 13 Weight percentage of FeO_{total} and TiO_2 of all samples to understand the economic importance.

6 Conclusion

The results of this study showed that the heavy mineral content in iron sand sediments from Purworejo-Kebumen, and Cilacap both consisted of pyroxene, amphibole, and heavy minerals such as hematite (0.5%-2.5% by weight), ilmenite (25-9.5% by weight), and magnetite (2-17.5% by weight) and light minerals consisting of quartz and plagioclase. The log (K_2O/Na_2O) and log (SiO_2/Al_2O_3) plots showed a similar composition of main elements and they were included in the greywacke classification. When the samples were normalized using the Upper Continental Crust, the principle elements of PW-KB and CL revealed a similar pattern, except for P_2O_5 where the PW-KB samples showed enrichment relative to CL.

All samples from the research area can be classified as being of mafic-igneous origin, which is supported by the Amajor diagram, showing that the samples from Purworejo are interpreted to originate from basalt and basalt + rhyolite/granite. The iron sand deposits in Kebumen are estimated to originate from basalt + ryolite/granite and ryolite/granite + basalt, while the deposits in Cilacap originate from basalt and ryolite/granite + basalt and show that the iron sands in Kebumen have the most acidic provenance. The Chemical Index of Alteration showed an intensity of weathering, as expected in a tropical climate. The ternary diagram displayed weak weathering.

Fe_2O_3 has a positive correlation with TiO_2 and V_2O_5. The iron sand from both areas have potential to be extracted with the main commodity iron, titanium, and vanadium. To fulfil this economic potential, further and more detailed research is needed, especially on measurable reserves and resources.

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