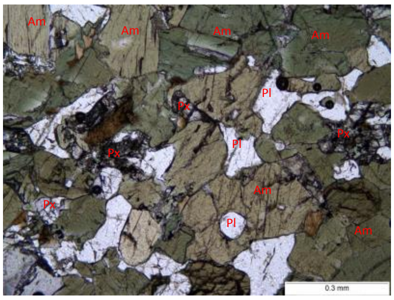

Figure 10: Photomicrograph of diorite from Erusu Akoko showing inclusions of plagioclase (Pl) in amphiboles (Am) and pyroxene (Px) in amphiboles. PPL

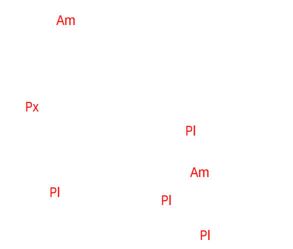

Figure 11: Photomicrograph of diorite from Erusu Akoko rock showing inclusions of plagioclase (Pl) in amphiboles (Am). XPL

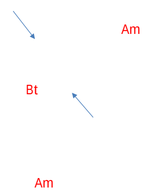

Figure 12: Photomicrograph of diorite showing biotite (Bt) surrounded by chlorite. The blue arrows pointing towards chlorite. Chloritization of biotite. PPL

Figure 13: Photomicrograph of diorite from Erusu Akoko showing biotite (Bt) cutting across amphibole (Am). Opaque mineral (Opq) PPL

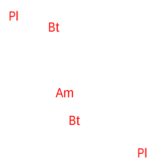

Figure 14: Photomicrograph of diorite from Erusu Akoko showing biotite (Bt) cutting across amphibole (Am) and plagioclase (Pl). XPL

Figure 15: Photomicrograph of diorite from Erusu Akoko showing alteration of feldspar to sericite. Biotite (Bt) occurring as inclusion in plagioclase (Pl). The blue arrow pointing towards sericite (XPL)

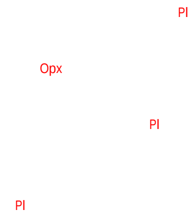

Figure 16: Photomicrograph of diorite from Erusu Akoko showing alteration of plagioclase feldspar (Pl) to sericite (XPL)

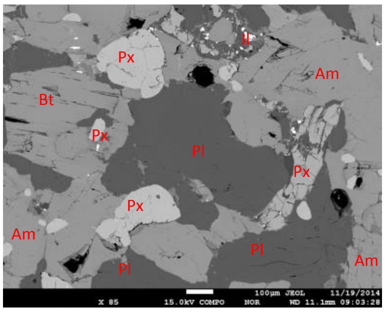

Figure 17: EPMA BSE image of diorite showing biotite, pyroxene, amphibole and plagioclase.

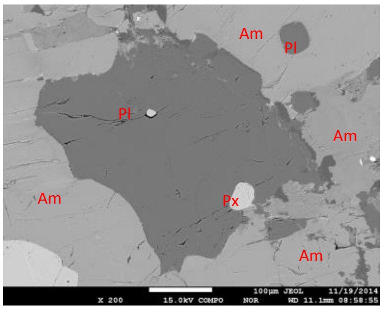

Figure 18: EPMA BSE image of diorite showing plagioclase, amphibole and pyroxene.

3.2 Mineral Chemistry

Biotite: The mineral chemistry of biotite for the mafic rock show the following: SiO_2 ;36. 64 wt %, Al_2O_3;14.02 %, FeO;16.76 %, MgO;13.23 %, K_2O;8.35 % while the total oxide is 92.53 wt % (Table 1).

Pyroxene: The mineral composition of pyroxene has the composition: SiO_2; 50.79 %, FeO;27.13 %, MgO;17.59 % and CaO;1.08 % (Table 2). The average of 52.48 % enstatite and 45.09 % ferrosilite. This composition confirms that the pyroxene present is hypersthene. The formula of the pyroxene from this result can be written as $MgFeSi_2O_6$ (Table 2).

Plagioclase: The mineral composition of plagioclase show; albite - 63.5 %, anorthite - 34.55 % and orthoclase -1.95 % (Table 3).

Amphiboles: The mineral composition of amphiboles shows that it is edenite-hornblende (Table 4).

Ilmenite: the mineral composition of ilmenite in the mafic rock has a composition of, SiO_2: 1.01 %, TiO_2: 52.52 % and FeO: 33.62 % (Table 5).

3.3 Major Element Chemistry of Diorite

The whole rock chemistry (Table 6) show compositions of the oxides as: SiO_2 (45.15 wt %), Al_2O_3 (14.04 wt %), CaO (7.58 wt %), Fe_2O_3 (16.01 wt %), MgO (5.65 wt %), K_2O (1.94 wt %), MnO (0.21 wt %), Na_2O (2.45 wt %), TiO_2 (3.59 wt %), P_2O_5 (0.51 wt %) and Cr_2O_3 (0.02 wt %).

3.4 Trace Element Composition of Diorite

The trace elements composition of the mafic rock show high level of composition of V, Cr, Zn, Cu, Co, Ni and Ba as, V: 312.6 ppm, Cr: 89.86 ppm, Zn: 136.5 ppm, Cu: 39.92 ppm, Co: 74.7 ppm, Ni: 71.59 ppm and Ba: 483.1 ppm, respectively (Table 7).

Table 1: Chemical Composition of Biotite in Diorite

Sample	17
SiO_2	36.64
TiO_2	3.18
Al_2O_3	14.02
Cr_2O_3	0.09
FeO	16.76
MnO	0.08
MgO	13.23
CaO	0.02
Na_2O	0.09
K_2O	8.35
Cl	0.1
$H^{2+}O$	1.83
Total	92.53
Si	5.93
AlIV	2.07
AlVI	0.60
Ti	0.39
Fe^{2+}	2.27
Cr	0.01
Mn	0.01
Mg	3.19
Ca	0.00
Na	0.03
K	1.72
Cations	16.22
CCl	0.06
OH	1.97
O	24
Fe/(Fe+Mg)	0.42
Mg/(Fe+Mg)	0.59

(AlIV: aluminium in tetrahedral site, AlVI: aluminium in octahedral site)

Table 2: Mineral Composition of Pyroxene in Diorite

Sample	17c	17r	mean
SiO_2	50.809	50.772	50.7905
TiO_2	0.026	0.04	0.033
Al_2O_3	0.406	0.441	0.4235
FeO	26.073	28.189	27.131
Cr_2O_3	0.065	0.043	0.054
MnO	0.537	0.499	0.518
MgO	17.418	17.754	17.586
CaO	1.642	0.517	1.0795
Na_2O	0.002	0	0.001
K_2O	0.034	0.041	0.0375
Total	97.01	98.3	97.655
TSi	2.004	1.983	1.9935
TAl	0	0.017	0.0085
TFe^{3+}	0	0	0
M1Al	0.019	0.003	0.011
M1Ti	0.001	0.001	0.001
$M1Fe^{3+}$	0	0.012	0.006
$M1Fe^{2+}$	0	0	0
M1Cr	0.002	0.001	0.0015
M1Mg	0.978	0.982	0.98
M2Mg	0.046	0.052	0.049
$M2Fe^{2}$	0.86	0.908	0.884
M2Mn	0.018	0.017	0.0175
M2Ca	0.069	0.022	0.0455
M2Na	0	0	0
M2K	0.002	0.002	0.002
Sum_cat	3.998	3.998	3.998
Ca	3.52	1.093	2.3065
Mg	51.948	52.204	52.076
Fe2_Mn	44.533	46.703	45.618
JD1	0.095	0.104	0.0995
AE1	0	0	0
CFTS1	0.104	0.701	0.4025
CTTS1	0	0.06	0.03
CATS1	0	0.052	0.026
WO1	3.445	0.288	1.8665
EN1	52.375	52.588	52.4815
FS1	43.981	46.207	45.094
Q	1.954	1.963	1.9585
J	0	0	0
WO	3.52	1.086	2.303
EN	51.948	51.878	51.913
FS	44.533	47.036	45.7845
WEF	99.984	100	99.992
JD	0.016	0	0.008
AE	0	0	0

(M1: Y octahedral site, M2: X octahedral site, JD: jadeite, AE; aegirine, WO: wollastonite, EN: enstatite, FS: ferrosilite, CAT: cation)

Strontium is high and Rb is very high in sample. Barium is high (483.06 ppm), Zr is also high but Hf and Th are both low in values.

3.5 Rare Earth Element of Diorite

The REE abundances are given in Table 8 and the chondrite-normalized REE plot display a negative Eu anomaly. In calculated terms, the europium anomaly is 0.832 while the cerium anomaly is 1.087 (Table 8). The ratio of lanthanum to ytterbium is 5.344 (Table 8), which shows an enrichment of light rare earth elements (LREE) and a depletion of heavy rare earth elements (HREE) in these rocks.

4. Discussion

Based on the petrographic studies the mafic intrusive rock can be given the name two-pyroxene diorite because of the presence of orthopyroxene and clinopyroxene. The strong pleochroic nature of the pyroxene suggests hypersthene which has been confirmed by the mineral chemistry (Table 2). The relationship between the pyroxene and the amphibole suggests that the pyroxene (anhydrous mineral) reacts with the hydrous melt in the presence of plagioclase to give amphiboles (hydrous mineral), this can be represented as ; Opx + Plagioclase 1 + H_2O = Amphibole + Plagioclase 2. Plagioclase 1 will be Ca-rich (anorthite) while plagioclase 2 will be Ca-poor. The mineral chemistry confirms the Plagioclase 2 as Ca-poor (Table 3).The presence of opaque minerals (ilmenite) around pyroxene in close association with amphiboles an indication that these reaction is gives off titanium (Ti^{4+}). The pyroxene-biotite relationship can be due to the reaction of orthopyroxene with alumina in the presence of potassium ions to give biotite and can be represented as; Opx + plagioclase + K^+ + H_2O = Biotite. The biotite is rimmed by a greenish mineral and indication that it is reacting to form chlorite.

Table 3: Chemical Composition of Plagioclase Feldspar in Diorite

Sample	17
SiO_2	59.15
TiO_2	0.035
Al_2O_3	24.775
FeO	0.04
MnO	0.015
MgO	0.005
CaO	7.195
Na_2O	7.31
K_2O	0.345
Total	98.9
Si	2.67
Al	1.317
Fe^{3+}	0
Ti	0.0015
Fe^{2+}	0.0015
Mn	0.0005
Mg	0.0005
Ba	0.0005
Ca	0.348
Na	0.64
K	0.0195
Cations	4.9995
X	3.9885

(Ab: Albite, An: anorthite, Or: orthoclase)

Table 4: Chemical Composition of Amphibole in Diorite

Sample	17c	17r	Average
SiO_2	43.81	44.28	44.05
TiO_2	1.096	1.010	1.053
Al_2O_3	9.825	10.02	9.920
FeO	15.41	15.02	15.21
Cr_2O_3	0.057	0.204	0.130
MnO	0.150	0.084	0.117
MgO	11.76	11.70	11.73
CaO	11.74	11.43	11.58
Na_2O	1.459	1.334	1.396
K_2O	1.278	1.211	1.245
Cl	0.078	0.074	0.076
Total	96.61	96.16	96.39
O_Cl	0.020	0.020	0.020
TSi	6.613	6.689	6.651
TAl	1.387	1.311	1.349
Sum(T)	8.000	8.000	8.000
CAl	0.359	0.471	0.415
CCr	0.007	0.024	0.016
CFe^{3+}	0.099	0.00	0.050
CTi	0.124	0.115	0.120
CMg	2.647	2.633	2.640
CFe^{2+}	1.763	1.757	1.760
Sum(C)	5.000	5.000	5.000
BFe^{2+}	0.083	0.140	0.1115
BMn	0.019	0.011	0.015
BCa	1.898	1.850	1.874
Sum(B)	2.000	2.000	2.000
ANa	0.427	0.391	0.409
AK	0.246	0.233	0.240
Sum(A)	0.673	0.624	0.649
Sum_cat	15.67	15.624	15.65
CCl	0.020	0.019	0.019
Sum_oxy	23.00	23.02	23.01

Table 5: Chemical Composition of Ilmenite in Diorite

Sample	17
SiO_2	1.012
TiO_2	52.52
Al_2O_3	0.162
FeO	33.62
Cr_2O_3	0.010
MnO	9.079
MgO	0.001
CaO	0.885
Na_2O	0.000
Total	97.29
Si	0.026
Al	0.005
Ti	1.004
Fe^{2+}	0.714
Cr	0.000
Mn	0.195
Mg	00.00
Ca	0.024
Na	00.00
Cations	1.968

Table 6: Bulk Rock Composition of Diorite (%)

Sample	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	MnO	Na_2O	TiO_2	P_2O_5	Cr_2O_3	LOI	Total
17	**45.15**	14.04	7.58	16.01	5.65	1.94	0.21	2.45	3.59	0.51	0.02	2.05	99.2

Table 7: Trace Element Composition of Diorite (ppm)

Sample	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Zr	Nb	Mo	Cs	Ba	Hf	Ta	Pb	Th	U
17	**312.6**	89.86	74.7	71.59	39.92	136.5	100.5	326	281.4	24.72	1.86	4.02	483.1	7.18	1.52	10.5	3.38	0.7

Table 8: Rare Earth Element of Diorite (ppm)

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
17	**27.45**	43.46	32.38	73.01	9.5	41.22	8.97	2.495	9.38	1.399	8.32	1.675	4.745	0.6	4.35	0.676

La_N/Yb_N	Gd_N/Yb_N	Eu_N/Eu_N^*	Ce_N/Ce_N^*
5.344	1.79	0.832	1.087

$Eu/Eu^* = Eu_N/(Sm_N \times Gd_N)0.5$; $Ce/Ce^* = Ce_N/(La_N \times Nd_N)^{0.5}$. Subscript N denotes Chondrite normalzed values. Normalized factors are from (Sun and McDonough, 1989).

Therefore, amphiboles and biotite can be said to have formed by hydration crystallization, the evidence of which is the resorbed pyroxene and oxide mineral (ilmenite) mantled by amphiboles and biotite (Figures 4-7) (Beard et al., 2004; Beard et al., 2005). The association of these minerals suggest that pyroxene is the earliest, because it occurs as inclusions in amphiboles and biotite. The amphiboles is quite earlier than biotite because the biotite cuts across the amphibole and plagioclase (Figures 13 and 14), this represents the normal crystallization of minerals in igneous rocks (Bowen, 1928).The plagioclase feldspar exhibit both albite and Carlsbad twinning an indication that it is of igneous origin. The petrographic study show the plagioclase alteration to sericite through a process called sericitization, common phenomenon in igneous rocks.

This could have resulted from the hydrothermal fluids reacting with the pores in the plagioclase a process which is usually associated with chloritization of biotite (Figure 12) (Que and Allen, 1996). The photomicrographs, BSE images and result from the mineral chemistry shows no zoning in any of the minerals. The Al_2O_3 in the pyroxene is extremely low (0.4 %). The aluminium content in the amphibole is high while TiO_2 is very low. The amphibole shows an Edenite-hornblende type which is calcium rich. The plagioclase in the mafic intrusive is oligoclase, an indication that it was formed at lower temperature in the later stage of crystallization and thus have inclusions of earlier crystallized minerals such as pyroxene.

The percentage of silica present (45.15 %) in the whole rock is an indication that the rock is basic or mafic in composition (Hafferen and O'Brien, 2010; Haldar, 2013). It is an indication that the rock evolved from MgO - FeO rich component which is typical of tholeiitic cumulates. The low Nd and high Sr isotopic ratios is characteristic of continental crust, whereas the upper mantle has high Nd and low Sr isotopic ratios (Best and Christiansen, 2001). The photomicrographs and BSE images of the minerals show no form of zoning an indication that the minerals were in equilibrium with the melt during crystallization.

5. Conclusion

Based on the mineral chemistry and the geochemistry of the studied rock, this mafic intrusive rock can be named as hypersthene-diorite. The presence of amphibole is an indication that the magma from which the rock was formed was hydrous in nature. The rock has not been affected by any form metamorphism and deformation based on texture. There is an enrichment of LREE and a depletion of HREE. The fact that the rock contains hypersthene, which is a high temperature mineral with amphibole and biotite forming from hydration crystallization, the hypersthene-bearing diorite can be said to have extensively retrogressed.

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