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Tectonic Geomorphology of Ultramafic Complex in Asera, North Konawe Regency

Geomorfologi Tektonik Kompleks Ultramafik di Daerah Asera, Kabupaten Konawe Utara

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Abstract- Ultramafic complex in Sulawesi have many potential from mining to environmental aspects. The process of weathering and tectonic is a key factor in understanding how to utilize these potential. Tectonic geomorphology by using morphometric indices and field observation has proven to be a beneficial method in distinguishing the topography and morphogenetic development of a region due to the complex interaction between erosional processes and tectonic movements. IAT measurement of 71 sub-basins shows that tectonic activity in the research area are divided into 4 classes with values ranging from 1,5 – 2,6. Field observation shows that morphologically the research area are faulted hills consist of peridotite, dunite and pyroxenite with various degree of weathering. The effect of weathering also reveal on the shape of sub-basins and drainage density in the research area. Tectonic activity present in the form of intensive joint on some parts, with no clear correlation with IAT Class.

keyword: Carbon capture storage, east Sulawesi ophiolite, morphometric indices, ultramafic, tectonic geomorphology,

Abstrak-*Kompleks batuan ultramafik di Sulawesi memiliki banyak potensi baik dari aspek bahan galian maupun lingkungan. Proses pelapukan dan tektonik merupakan faktor kunci dalam memahami bagaimana potensi tersebut dapat dimanfaatkan. Geomorfologi tektonik menggunakan indeks geomorfik dan pengamatan lapangan telah terbukti sebagai metode yang dapat membedakan pembentukan topografi dan morfogenetik sebuah wilayah dikarenakan interaksi yang kompleks antara proses erosional dan aktivitas tektonik. Pengukuran IAT pada 71 sub-DAS menunjukkan bahwa aktivitas tektonik di daerah penelitian terbagi menjadi 4 kelas dengan nilai berkisar antara 1,5 – 2,6. Pengamatan lapangan menunjukkan bahwa morfologi di daerah penelitian terdiri dari bukit sesar yang tersusun oleh peridotit, dunit dan piroksenit dengan beragam tingkat pelapukan. Efek dari pelapukan tersebut juga tercermin pada bentukan sub-DAS dan kerapatan pola pengaliran di daerah penelitian. Aktivitas tektonik terlihat pada kekar yang intensif pada beberapa lokasi namu tidak memiliki korelasi yang jelas dengan kelas IAT.*

Kata Kunci: *Penyimpanan karbon, ofiolit Sulawesi timur, indeks geomorfik, ultramafik, geomorfologi tektonik.*

INTRODUCTION

Ultramafic complex in Asera, North Konawe Regency is a part of East Sulawesi Ophiolite (ESO) which span from Gorontalo Bay through the East Arm and into the South-east Arm (Kadarusman et al., 2004). ESO is considered one of the three largest ophiolite complexes in the world and comprise of mafic to ultramafic rocks (Baillie & Decker, 2022; Surono, 2010). Ultramafic rocks in the Konawe Regency mainly consist of peridotite to dunite and has been mined to extract their nickel content. The formation of nickel deposit is associated with weathering process of ultramafic source rocks (Jahidin et al., 2020).

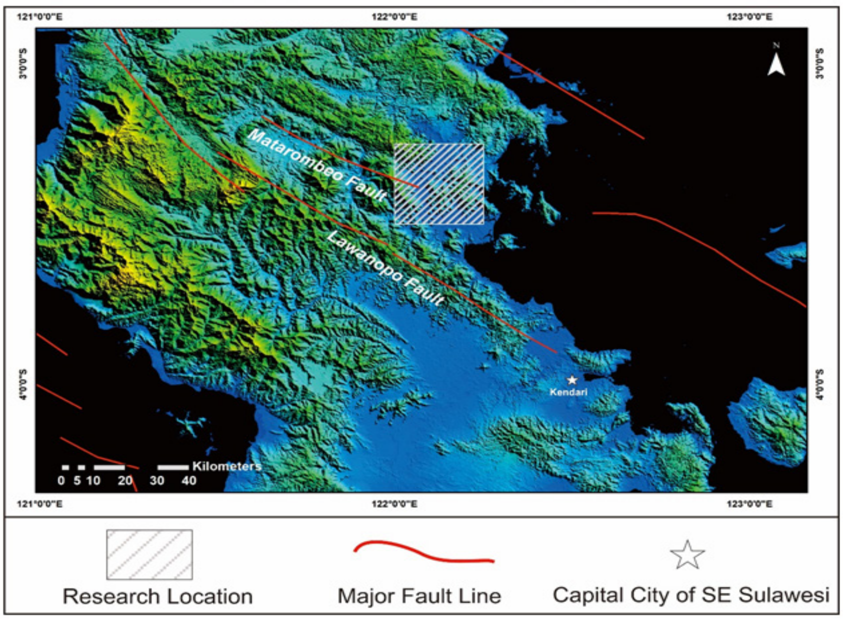
In addition to nickel deposit mining, ultramafic rocks can be used as *in-situ* Carbon Capture Storage (CCS) (Rielli et al., 2021). CO_2 capture from mineral carbonation injection through fracture have a main advantage which is low risk of release because the CO_2 is converted into stable carbonate minerals (Kelemen et al., 2019). Weathering and tectonic plays a significant role in ultramafic rocks for its association of nickel laterite deposits and CCS potential.

Geomorphological development in ultramafic complex will be influenced by tectonic and weathering due to its origin and weathering susceptibility. Tectonic geomorphology can be used to distinguished the topography and morphogenetic development of a region due to the complex interaction between erosional processes and tectonic movements (Luthfi Faturrakhman et al, 2023.; Topal & Özkul, 2018). This paper aims to determine whether tectonic geomorphology using morphometric indices can assist in identifying potential area of interest for further research.

RESEARCH LOCATION

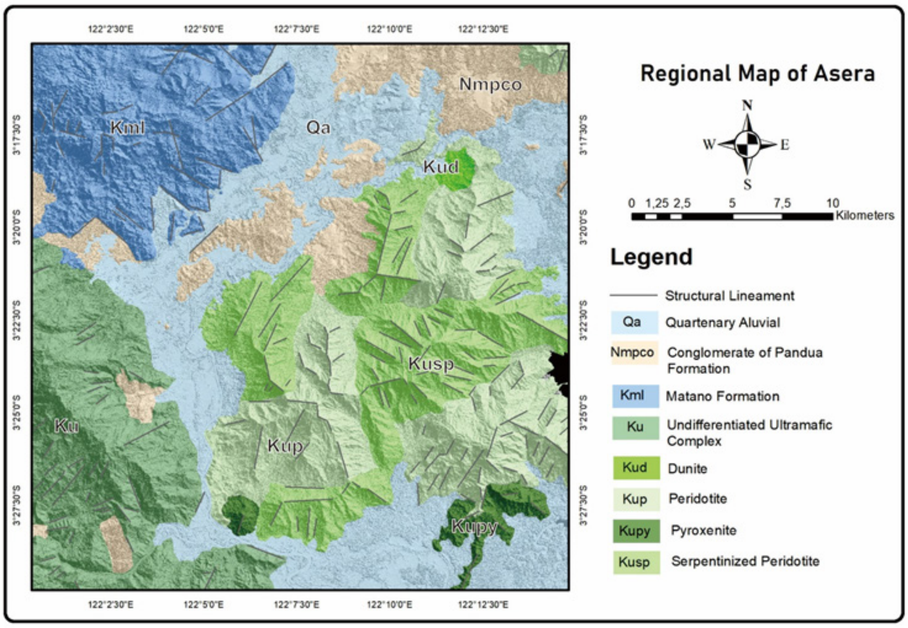
This research is located in Asera, North Konawe Regency, South East Sulawesi Province (Figure 1). Research area shaped by tectonic processes as faulted mountain/hills which stretches along the south-eastern arm of sulawesi (Poedjoprajitno 2012). This area is composed of two different types of rock formations, namely rocks that characterize continental crust and rocks that characterize oceanic crust. (Rusmana et al., 1993a). Cretaceous Ophiolite Complex (Ku) is the oldest rock formation in this area and consist of mafic to ultramafic rocks. The Ophiolite Complex in East Arm of Sulawesi are emplaced during collision of South East Asia and Australia (Hall, 2012; Silver et al., 1983) The Matano Formation (Km) was formed in the Upper Cretaceous and is composed of calcilutite with intercalation of chert and shale. These formations are consist of rock with oceanic crust characteristic and overlain by Pandua Formation with continental crust characteristic.

Pandua Formation (Tmpp) is a part of Celebes Mollases which deposited from post-orogenic after a major collision (Nugraha *el al.*, 2022). Pandua Formation composed of conglomerate with serpentinite fragments, mudstone and sandstone with a minimum thickness of 2000 m (Nugraha et al., 2022). Quaternary Alluvium (Qa) is the youngest rock units with unconsolidated pebble, gravel and sand (Figure 2).



Source: Soehaimi et al (2021)

Figure 1. Location of research area and its surrounding fault system.



Source: Rusmana et al., (1993)

Figure 2. Regional map of Asera

TECTONIC GEOMORPHOLOGY

Tectonic geomorphology analysisis using morphometric indices has been used profoundly to to identify relative tectonic deformation and weathering process over a large area (Bull, 1984; Hidayat et al., 2021). This research used three morphometric indices: 1) mountain front sinuosity (Smf), 2) basin shape index (Bs), and 3) drainage density. These morphometric indices are then quantified to determine the relative tectonic activity (IAT) (Table 1). IAT can be used to identifying active tectonic and tectonic deformation of a large region (El Hamdouni et al., 2008).

Mountain Front Sinuosity (Smf)

Mountain Front Sinuosity (Smf) is a morphometric indices used to compare the rate of tectonic activity with weathering. A mountain front with prominent tectonic activity will have a relatively straight mountain front compared to irregular front from low tectonic activity (Bull & McFadden, 1977; El Hamdouni et al., 2008).

Basin Shape Index (Bs)

Basin shape index (Bs) is a morphometric indices used to differentiate tectonic activity and weathering from the geometry of adjacent basins in the research area. Basin with low tectonic activity and intensive weathering will have a circular shape compared to the angular shape of a basin with high tectonic activity and minimal weathering (El Hamdouni et al., 2008).

Drainage Density (Dd)

Drainage density (Dd) is a morphometric indices used to measure the density of streams in a basin. Basin with high tectonic activity will have a concentrated streams from physicaly erosive lithology (Hidayat et al., 2021; Horton, 1945; Sukiyah, 2009).

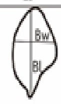
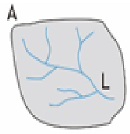
Index of Relative Tectonic Activity (IAT)

Index of tectonic activity is a method proposed by El Hamdouni et al (2008) to evaluate tectonic activity based on morphometric indices. This index is beneficial in understanding the morphology and topography in relation of its tectonic activity over a large area. IAT is obtained from the different classes average of morphometric indices used in this research and divided in to 4 tectonic classes.

METHOD

This research will combine topographical measurement using GIS software and field work . Subbasins will be generated based on 3rd stream order to facilitate interpretation the various morphometric indices used in numerical terms (Singh et al., 2020). The data used in morphometric indices will be using IFSAR Digital Surface Model (DSM) courtesy of Geological Survey Center. Field work will be conduct to validate the morphology development, lithological properties and structural manifestation in the research area.

Table 1. Morphometric Indices used in this research

Morphometric Indices	Mathematical Formula	Measurement Procedure	Explanation	References
Mountain Front Sinuosity (Smf)	$\frac{Lmf}{Ls}$		Smf < 1,1 : Class 1 1,1 < Smf < 1,5 : Class 2 Smf > 1,5 : Class 3	Bull & McFadden (1977) el Hamdouni et al (2008)
Basin Shape Index (Bs)	$\frac{Bl}{Bw}$		Bs > 4 : Class 1 3 < Bs < 4 : Class 2 Bs < 3 : Class 3	Bull & McFadden (1977) el Hamdouni et al (2008)
Drainage Density (Dd)	$\frac{\sum L}{A}$		5,5 < Dd < 8,2 : Class 1 4,14 < Dd < 5,5 : Class 2 Dd < 4,14 : Class 3	Horton (1945) Sukiyah (2009) Hidayat et al (2021)
Index of Relative Tectonic Activity (IAT)	$\frac{S}{n}$	S : Sum of class values of each morphometric indices n : Sum of morphometric indices used	IAT 1 - 1,5 : Very High Tectonic Activity IAT 1,5 - 2 : High Tectonic Activity IAT 2 - 2,5 : Moderate Tectonic Activity IAT > 2,5 : Low Tectonic Activity	el Hamdouni et al (2008)

RESULT

The measurement of IAT from 71 sub-basins in the reseach area has been calculated and gave an insight to the tectonic activity in the research area (Figure 3;Table 2). The measurement of each morphometric indices will be explained in detail below :

Mountain Front Sinuosity (Smf)

The measurement of 39 mountain fronts in the research area has been able to determine that the mountain fronts are divided into 3 tectonic classes with values ranging from 1.01 to 2.6. Relatively straight mountain fronts are presents in the southern parts of the research area particularly near the Cretaceous Ultramafic Complex (Ku) and aluvial deposit (Qa) border. Joint denisity analysis from this area shows that the density is ranging from 35 – 278 joint/m^2. Middle and northern parts of the research area predominantly composed of irregular mountain fronts of class 3 with joint density ranging from 53 – 119 joint/m^2 (Figure 3A).

Basin Shape Index (Bs)

The measurement of 71 sub-basins shapes has been able to determine that the sub-basins in the research area are divided into 3 tectonic classes with values ranging from 0.3-4.6. Sub-basin in the reseach area are predominantly circular in shape with some angular shape in the western parts of research area. Circular shape of the sub-basin in the research area shows that physical weathering from lateral incision is a significant factor in shaping the basin shape in this area. Ultramafic rock in this area are mainly composed of peridotite and serpentinized peridotite which have a low tolerance towards weathering. Jahidin et al (2020) has been examined the magnetic susceptibility from rock sample and concluded that the weathering level of ultramafic rocks in this area is in the continue state (Figure 3B).

Drainage Density (Dd)

The measurement of 71 sub-basins drainage density has been able to determine that the drainage density in research area are divided into 2 classes with values ranging from 4,4 – 6.3. Class 1 which indicate a higher tectonic activity area scattered within the Cretaceous Ophiolite Complex (Ku) in the middle part of research area. Class 2 is the predominant class and scattered within the Cretaceous Ophiolite Complex (Ku) and Matano Formation (Km; Figure 3C).

Index of Relative Tectonic Activity (IAT)

IAT is measured from the average calculation of morphometric indices previously. IAT in the research area are divided into 4 classes with values ranging from 1,5 – 2,6. IAT class 3 (moderate tectonic activity) are the predominant class and are scattered in all of the reseach area with some parts are adjoined by IAT class 2 (high tectonic activity). IAT class 1 and 4 are scattered limited in some parts of the middle and northern parts of the research area respectively (Figure 3D).

Table 2. Classification of relative tectonic activity index (IAT) calculated from other geomorphic indices (Bs, Smf, Dd)

Sub_ Basin	Bs	Smf	Dd	S/n	IAT
1	2	3	1	2	2
2	2	3	1	2	2
3	1	3	1	1,6	2
4	3	2	2	2,3	3
5	3	-	2	2,5	3
6	3	-	1	2	2
7	3	-	2	2,5	3
8	2	2	2	2	2
9	3	2	2	2,3	3
10	3	-	2	2,5	3
11	3	-	2	2,5	3
12	3	-	2	2,5	3
13	3	2	2	2,3	3
14	3	2	2	2,3	3
15	3	3	1	2,3	3
16	3	3	2	2,6	4
17	2	3	1	2	2
18	3	2	2	2,3	3
19	2	1	2	1,6	2
20	3	-	1	2	2
21	3	1	2	2	2
22	3	-	2	2,5	3
23	3	2	2	2,3	3
24	1	-	2	1,5	1
25	3	2	1	2	2
26	3	-	2	2,5	3
27	3	2	2	2,3	3
28	3	-	1	2	2
29	3	-	2	2,5	3
30	3	-	2	2,5	3
31	3	1	1	1,6	2
32	3	-	2	2,5	3
33	3	-	2	2,5	3
34	3	-	2	2,5	3
35	3	-	1	2	2
36	3	-	1	2	2
37	2	3	1	2	2
38	3	3	2	2,6	4
39	3	3	1	2,3	3
40	3	3	2	2,6	4
41	3	3	1	2,3	3
42	3	3	2	2,6	4
43	3	2	2	2,3	3
44	3	-	2	2,5	3
45	3	3	2	2,6	4
46	2	3	2	2,3	3
47	3	2	2	2,3	3
48	3	2	2	2,3	3
49	3	3	2	2,6	4
50	3	-	2	2,5	3
51	2	-	1	1,5	1
52	3	-	2	2,5	3
53	3	-	1	2	2
54	3	3	1	2,3	3
55	3	3	1	2,3	3
56	3	-	1	2	2
57	3	-	2	2,5	3
58	3	3	2	2,6	4
59	3	3	1	2,3	3
60	3	1	1	1,6	2
61	3	2	2	2,3	3
62	3	1	2	2	2
63	3	-	2	2,5	3
64	3	3	1	2,3	3
65	3	-	2	2,5	3
66	3	-	2	2,5	3
67	3	-	1	2	2
68	3	-	2	2,5	3
69	3	-	1	2	2
70	3	-	2	2,5	3
71	3	2	2	2,3	3

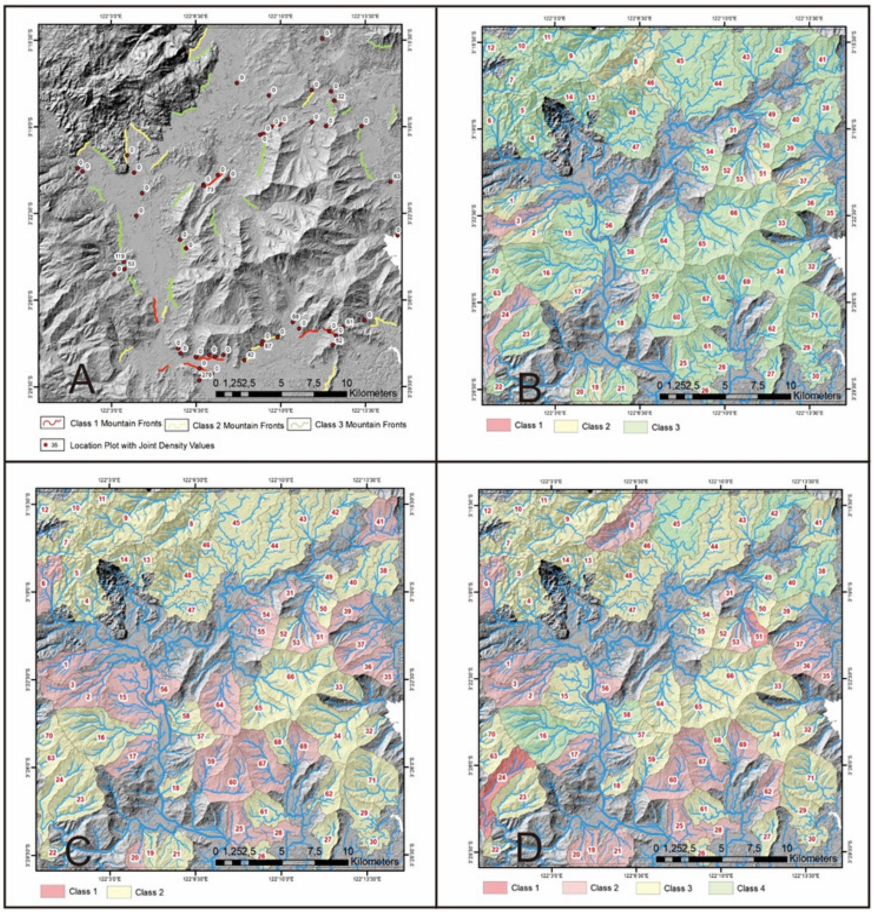


Figure 3. A. Mountain fronts and its correlation with joint density measurement
B. Basin shape index measurements and its classification
C. Drainage density measurement and its classification
D. IAT classification of the reseach area.

Field Observation

Field observation shows that morphologically the research area are faulted hills surrounded by aluvial plain and karst tower (Figure 4A). The slope ranges from 20˚ - 45˚, V-shaped valley, land-covered by natural vegetation, mostly palm oil on the middle-lower slope. This zone was also converted into a mining area which greatly changed the local morphology and exogenic processes. Triangular facet can be recognized in the upper slope, extended along Hialu Mountain on the westward (Figure 4B).

Ultramafic rocks in the study area are composed of peridotite, pyroxenite and dunite with low to moderate weathering. (Figure 4C). Serpentization occurs extensively on certain locations and are ussualy accompanied with the occurence of intensive joint of the rock bodies. Joint density measurement of ultramafic rocks in the research area are ranging from 32 – 278 Joint/m^2 (Figure 4D).

DISCUSSION

Tectonic geomorphology using morphometric indices has been able to determine the Relative Tectonic Activity in the research area. Morphometric indices analysis of mountain fronts and basin shape shows that tectonic and weathering is a contributing factor in shaping the landscape in research area. High tectonic activity will have an effect on shaping the mountain fronts into a straight line like in the southern parts of the research area. Lasolo strike-slip faults are projected to be the main contributing factor of the tectonic activity in this parts.

The shape of sub-basin in the research area are dominated by circular shape which indicated that lateral erosion from physical weathering is occuring intensively. Drainage density for most of the sub-basin in the research area also shows a moderate to high density in class 1 and 2. Ultramafic rocks rich in olivine and pyroxene are very susceptible to weathering process based on Goldich dissolution series. Intensive weathering will contribute to circular basin shape and dense drainge pattern from physical incisions.

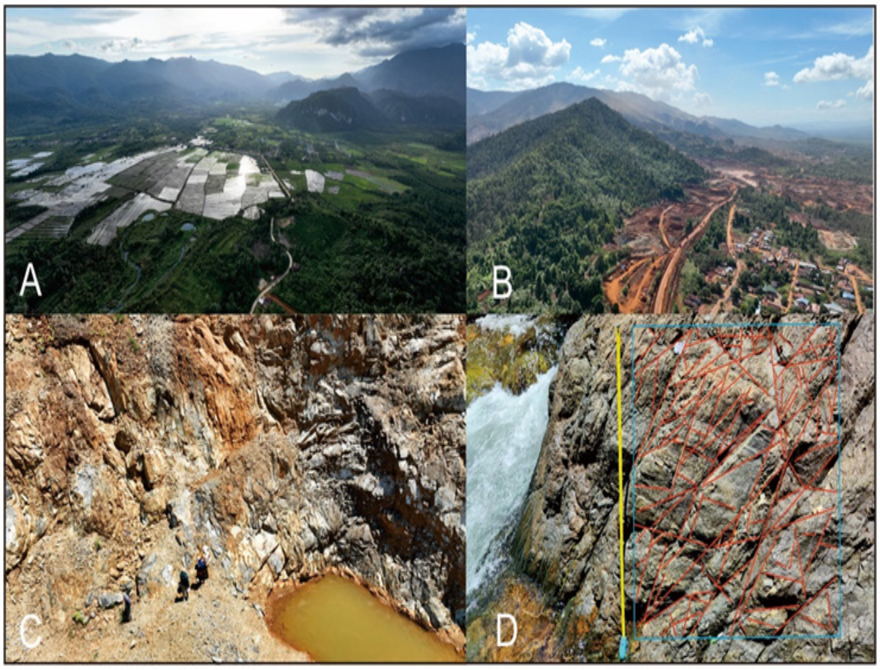


Figure 4. A. Faulted hills surrounded by aluvial plains and karst tower.
B. Triangular facet in the ultramafic complex
C. Serpentinize Peridotite with intensive joint
D. Joint density measurement in ultramafic rock.

IAT analysis from 71 sub-basins shows that the research area are divided into 4 classes which is class 1 (2% of total area), class 2 (28% of total area), class 3 (64%) and class 4 (6% of total area). Class 3 (moderate tectonic activity) indicate that there is a balance in tectonic and weathering activity in the research area. Tectonic manifestasion can be observed from the shape of mountain fronts with some shows triangular facet. Rock bodies in the research area are also shows intensive joint with some ranges into the upper 200 Joint/m^2.

However, based on this reseach there is no clear correlation between the intensity of joint density and tectonic activity. This is interpreted due to the joints are formed from older tectonic activity. Tectonic geomorphology are constraint to identify Neotectonic (upper part of Miocene – Quarter). Field observation has found that the ultramafic rocks consist as fragments in conglomerate units of Pandua Formation ages Upper Miocene (Nugraha el al., 2022).

CONCLUSION

Tectonic geomorphology analysis combined with field observation has been able to analyze the influence of tectonics and weathering in the utramafic complex. Analysis of morphometric indices has been able to identify the area of intensive tectonic and weathering which can be used to determine potential area of nickel deposits. However tectonic geomorphology analysis shows that there is no clear correlation between IAT class and fracture intensity for CCS exploration aplication. This is due to the joints are formed from older tectonic activity and the morphological aspect of the area has been changed.

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