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Physico-Chemical Properties and Mineral Identification of Salt Licks Soil in Segaliud Lokan Forest Reserve

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ABSTRACT

This study intended to describe the physicochemical and mineralogical properties of salt licks discovered in Segaliud Lokan Forest Reserve. The salt licks in this forest reported to be visited and used by wildlifes via camera trap studies. In order to understand this wildlife's behavior, the physicochemical and mineralogical properties of the salt lick especially the salt lick soil are important to determine the cause of the wildlife visitation. Five salt licks area as well as controlled soils were selected. Water and rock samples were also collected for the comparison study. The physical characteristic of licks soil shows pH ranges from slightly acidic to alkaline, high moisture content (23.30% – 59.35%), wide range of organic matter content (0.38% – 9.65%) and electrical conductivity range between 41.82 µS/cm to 243.32 µS/cm which is higher than the controlled soils. The soil texture from the salt licks soils is mostly classified as loam. The result of chemical analysis shows that the concentration of elements is higher in the lick soil compared to the controlled soil such as Ca (1101.92 mg/kg – 11551.64 mg/kg), K (767.32 mg/kg – 2432.11 mg/kg), Na (85.83 mg/kg – 754.20 mg/kg), Mg (986.05 mg/kg – 5843.29 mg/kg) and P (47.23 mg/kg – 290.215 mg/kg). Water samples from salt licks area are rich in Ca (637.67 mg/L – 3074.25 mg/L) and Na (572.35 mg/L – 2554.63 mg/L) compared to river nearby. The mineral analysis indicated the appearance of clay such as illite, chlorite and smectite. As a conclusion, the salt lick soil's pH varies from slightly acidic to alkaline (5.38 – 8.98) compared to controlled soils (4.54), The salt lick surface soils also show higher percentage of moisture content (69.38%) and soil electrical conductivity (78.41%) difference compared to controlled soils. Meanwhile the organic matter percentage in salt lick soils is slightly lower (48.85%) than the controlled soils (51.11%). The salt lick soils also exhibit higher elements concentration than the controlled soils such as average concentration of Ca (96.14%), K (86.09%), Na (89.51%) Mg (91.38%) and P (86.78%).

Keywords: Mineralogy, physico-chemical properties, salt lick, soil, water

INTRODUCTION

Salt licks are places where animals visit the place for geophagic activities (Panichev *et al.,* 2012; Lazarus *et al*., 2019). Natural occurring salt licks can be identified by bite marks or foot prints of animals in the wild (Lameed & Adetola 2012; Molina *et al.,* 2014) whereas artificial salt licks are made by humans in the form of blocked or bagged for farming purposes (Brightsmith, 2004). Natural mineral licks often exist along river banks (Kreulen, 1985; Diamond *et al.,* 1999) and also can be found within forest which is located away from the rivers (Matsubayashi *et al.,* 2007; Tobler *et al.,* 2009).

The frequent usage of natural licks by wildlife has resulted in many studies focusing on describing the physical characteristic of the salt lick, chemical and mineralogical composition and types of animals visiting the salt licks (Molina *et al.,* 2014; Matsubayashi *et al.,* 2007). Previous studies suggest that geophagy activities is a process where wildlife supplementing their diet with several nutrients such as N, Ca, C, P, Mg, Na, K, Fe, Cu, Zn, Cl or I (Matsubayashi *et al*., 2007; Ayotte *et al.,* 2006). Apart from mineral intake for their diets, wildlife also visits salt licks to counter the adsorption of dietary toxin by ingesting certain types of clay such as kaolinite (Kreulen, 1985; Diamond *et al.,* 1999) and act as buffering capacity (Kreulen, 1985; Ayotte *et al.,* 2006).

Buffering capacity defined as the ability of solution to counteract pH changes. For example, in terms of livestock studies conducted by Rolinec *et al.* (2018) indicated that the piglet's stomachs is higher than the optimal range because the first feed is colostrum, and for pigs as a standard protein, it is considered the protein of sow's milk, which can be affected by the health status of sows (Rolinec *et al.,* 2012). Irregular intake of large amount of feed may increase the pH values of the stomach above 5 and may persist for a few days (Lawlor *et al.,* 2005). Increased gastric pH in weaned pigs leads to decreased digestion and also diarrhea (Yen, 2000). When this situation is applied in wildlife's diet, visiting the salt licks is the only way to counteract the dietary toxin and to keep healthy.

Beside from functioning as mineral resources, salt lick area is considered as critical and crucial for wildlife (Primack, 1993). It has significant influence on the density and structure of population, distribution of wildlife and carrying capacity of habitats (Montenegro, 2004). Salt licks are also believed to attract large number of wild animal species (Blake *et al.,* 2010). Types of species visiting salt licks are mammals and birds, specifically frugivores and herbivores to consume soil or drink water (Kreulen, 1985; Diamond *et al.,* 1999). Composition of species visiting salt lick and frequency of visitation may vary from one lick to another lick (Tobler *et al.,* 2009). The variation is due to the abundance level of mineral composition in the soil or water between different salt lick (Abrahams, 1999).

Only a few studies have been conducted in Southeast Asia, especially Malaysia regarding the relationship between natural licks and wildlife distribution (Matsubayashi *et al.*, 2007). Specifically, studies focusing on the physico-chemical properties and elements concentration of salt licks in Sabah are lacking. Thus, the aim of this work is to determine the physico-chemical properties and elements concentration as well as mineral identification found in salt lick soils in Segaliud Lokan Forest Reserve and to compare the elements concentration between lick soils and non-lick soils. In addition, this study reveals key information about the elements concentration in salt lick soils engulf by wildlife.

MATERIALS AND METHODS

Description of Study Area

The study area was performed at Segaliud Lokan Forest Reserve (SLFR) located in Sandakan, Sabah bound to latitude 05° 25'' N - 05° 35'' N and longitude 117° 30'' E - 117° 37'' E as shown in Figure 1. The sampling location are selected based on the salt lick locality found in the forest reserve. Located in tropical climate, the soil is exposed to high weathering (Ling *et al.,* 2023) and leaching of bases minerals. This study area consists of two rock formations. The oldest rock unit found is Kulapis Formation, aged Eocene to Middle Miocene. Kulapis Formation is composed entirely of consolidated redbed marine sediments where the interbedded sandstone and mudstone are red in colour (Clennell, 1991). The main lithologies for this formation are greywacke, sublitharenite, calcareous lithic arenite and laminated mudstone (Hutchison, 2005). Both the salt lick soils and controlled soils are taken from the same formation. The salt lick soil locations were chosen based on the camera trap that show the presence of wildlife using the licks whereas the controlled soil location were sampled approximately 500 m away from the salt lick location. The main difference of the salt lick areas and control area is the presence of wildlife engulfing the soils. The lack of wildlife in the control areas indicates that the location is not crucial in supporting the well-being of the animals.

Soil, Water and Rock Sampling

This study uses two types of soil sampling; vertically and horizontal subsurface sampling. These types of sampling were used to identify the variation of mineral content on the surface and according to depth. For salt lick soil samples, vertical sampling is done by using a one-meter-long PVC pipe which is hit using a hammer until it reaches the hard bedrock depth. The pipe is then sealed on both ends to prevent any contamination. Collected core samples were extruded once it reached the laboratory and subdivided into 5 cm and 10 cm intervals depending on the depth obtained. Horizontal sampling is performed by removing a thin layer of the top soil before collecting the soil samples around 1 kg each. The depth for the horizontal soil sample is 5 cm deep from the soil surface. Controlled soil samples were also taken approximately 500 m away from salt lick area for comparison in physico-chemical properties and elements concentration with salt lick soils. The soil samples were stored in an airtight ziplock bags to avoid contamination. Water samples were taken from the running surface water or any water collected on the surface of the licks (Figure 2). The bottle and cap were rinsed using the water sample before collecting for water samples. Nitric acids (2%) were added into the water samples for preservation. Fresh rock samples were also taken as hand specimen. One rock sample (weathered sandstone) was taken from the outcrop found in salt lick SL59 and two rock samples (sandstone and mudstone) were taken from SL60. The rest of the rock samples were taken from outcrop along the forest road in the study area. All samples were labelled accordingly. A total of 34 salt lick soil, 5 controlled soil, 17 water samples and 5 rock samples were collected.

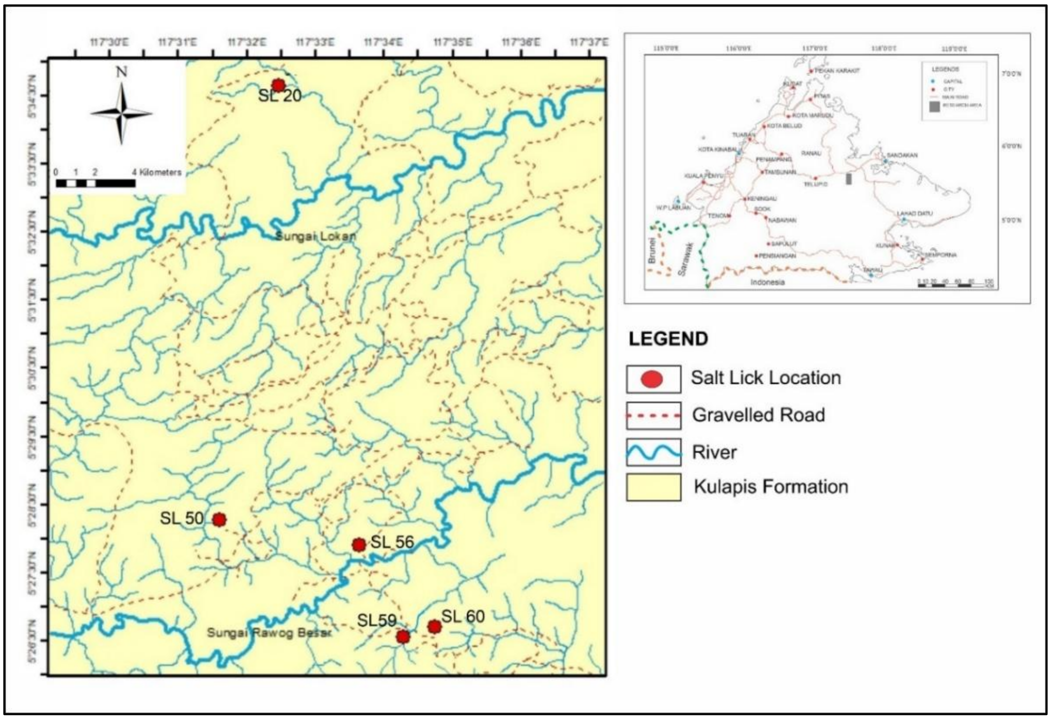

Figure 1. Geological map of study and sampling stations in Segaliud Lokan Forest Reserve

Figure 2. Water sampling carried out over a small flowing river cutting through salt lick SL59

Experimental Analysis

As soon as the samples reach the laboratory, the samples were tested for physico-chemical parameter analysis (pH, moisture content, organic matter and electrical conductivity). The soil samples were later air-dried as preparation for particle size distribution (texture) by following the British Standard method (BS1377:1990). The water samples were placed in the refrigerator as soon as it reached the laboratory. The test conducted for the water samples are pH, electrical conductivity, total dissolved solids and elements concentration.

The metal digestion process for soil samples were conducted using HCl: HNO_3 (aqua regia) mixture with 1:3 ratio based on the USEPA 6010D method. One gram of air dried, powdered and sieved through 63 µm mesh soil sample were weighed and added with 14 ml aqua regia solution and left overnight. The sample were then filtered through the Whatman 0.45 µm cellulose nitrate filter membrane to remove any suspended particles for cations analysis. Water samples were also filtered and diluted in the same manner. The Inductively Coupled Plasma (ICP- OES) were performed using Perkin Elmer Optima model 5300DV Spectrometer. Before performing an ICP OES analysis, a standard dilution stock solution of 100 mg/L as made in accordance with the International Certified Reference Materials (CRM) to calibrate the instrument. The standard reference materials (SRM) analysis calculations were performed with an accuracy range of 80%-120% in order to assess the acid digestion method's approriateness. Five reagent blanks were analyzed to determine the contamination before proceed to the ICP-OES analysis. All soil samples and water samples were performed in triplicate.The sample were analyzed to detect Ca, K, Na, Mg and P. Reading establish were recorded by the spectrometer and raw data were generated by the WinLab32 software.

Petrographic analysis was conducted using a petrographic microscope LEICA DM2500 by observing thin sections. Scanning Electron Microscopy (SEM) test were conducted to examined the morphology of the clay found in the soil samples. Five grams of air-dried soil samples were used for SEM analysis. The soil samples were coated using gold coater. Sample analysis was performed using JEOL JSM- 35 6100 microscope and Link An 10/855 Analyser.

RESULTS AND DISCUSSION

Physico-chemical Properties

The salt lick soils range from slightly acidic to slightly basic (pH 5.38 – 8.98) in nature whereas the controlled soil shows acidic soil (pH 4.54). The ranges for moisture content (25.28 - 39.00%) and organic matter (0.38 - 5.28%) shows higher value than the controlled soil (Table 1). The electrical conductivity for salt lick soil also shows higher reading ranges between 41.82 µS/cm to 243.32 µS/cm compared to controlled soil (50.31 µS/cm). The higher values of moisture content (69.38%) supported by the higher percent of particle size of clay and silt particles than sand (Table 1). The percentage of the particle size varies from each salt licks. Soils with finer particles (clay and silt) have a larger surface area than those with coarser particles, and a large surface area allows soil to hold a more water (Chakraborty and Mistri 2015).

The surface soil of salt lick SL56 was gravelled as shown in Figure 3. The surface soil was also submerged in water (Figure 4) believed to be sourced from a spring (Figure 5). This confirms the high moisture content (%) and organic matter (%) with animal's excrement in the vicinity of the samples taken. The electrical conductivity for mud lick soils similarly exhibited higher reading compare to controlled soils indicating the concentration of salts is greater (Othaman *et al.,* 2020). With exception of SL59 where electrical conductivity reading (41.82 µS/cm) vary with the rest of the licks (167.31 µS/cm - 243.32 µS/cm). Lower electrical conductivity values suggest that less soluble salts are readily available in the soil (Othaman *et al.,* 2020). The existence of salt licks area was depending on the accumulation of salt. Jakovljeviã *et al.* (2003) reported that salt found in the salt lick areas were the products of weathering depending on the weathering rate and leaching rate of the weathered resulting products.

Table 1. Mean value for physico-chemical parameters and elemental concentration analysis for soil samples.

Sample	pH	MC (%)	OM (%)	EC (uS/cm)	Particle Size (%)				Concenration (mg/kg)				
					Sand	Silt	Clay	Texture	Ca	K	Na	Mg	P
Surface Soil													
SL20 (n=4)	8.98	25.28	0.38	236.58	34.80	35.04	30.18	Clay Loam	8318.50	2432.11	529.04	5843.29	261.78
SL50 (n=5)	6.95	39.00	3.92	243.32	31.30	36.61	32.11	Clay Loam	11551.64	1456.29	199.60	2501.74	256.29
SL56 (n=3)	6.04	36.00	5.28	224.39	52.60	29.39	18.01	Sandy Loam	1101.92	980.54	154.56	1442.14	128.48
SL59 (n=6)	5.38	36.28	4.80	41.82	53.50	26.92	19.24	Sandy Loam	1252.95	767.32	85.83	986.05	47.23
SL60 (n=6)	7.53	23.30	2.50	167.31	16.1	58.19	25.68	Silt Loam	2807.07	1920.97	647.67	4825.05	273.83
Controls (n=5)	4.51	17.04	3.79	51.72	46.40	30.96	22.29	Loam	1006.254	1220.702	189.424	1470.738	141.572
Subsurface Soil													
SL59 (1) (n=2)	6.57	54.62	9.40	51.05	85.30	2.95	11.74	Loamy Sand	2204.215	760.705	83.305	1373.79	128.235
SL59 (2) (n=2)	6.63	50.36	6.86	61.44	60.15	19.25	20.60	Sandy Clay Loam	2129.445	965.45	123.645	1701.525	173.23
SL59 (3) (n=2)	6.59	48.22	8.87	71.76	55.57	25.94	18.49	Sandy Loam	2216.025	977.975	122.115	1705.71	207.73
SL59 (4) (n=2)	6.59	59.35	9.65	75.09	43.85	31.54	24.62	Loam	2435.78	1105.42	149.23	1806.945	290.215
SL60 (a) (n=2)	8.32	27.95	2.05	94.32	16.29	61.02	22.69	Silt Loam	3901.57	2253.80	577.98	5573.05	bdl
SL60 (b) (n=2)	8.44	30.10	2.11	94.92	16.96	62.84	20.20	Silt Loam	3756.79	2158.61	607.55	5592.49	78.58
SL60 (c) (n=2)	8.77	31.56	1.74	133.68	12.58	33.21	54.21	Loam	4333.21	2216.83	754.20	5613.35	174.85

1 0cm-10cm
2 10cm-20cm
3 20cm-30cm
4 30cm-40cm
a 0cm-5cm
b 5cm-10cm
c 10cm-15cm
bdl below detection limit

Figure 3. Gravelled environment of salt lick SL56

Figure 4. The surface soil of SL56 was wet believed to be influenced by spring water nearby

Figure 5. Spring found in salt lick SL56

SL56 and SL59 soil exhibit slightly higher organic matter content with 26.09% and 23.70% difference compared to other salt lick for surface soils. In addition, SL59 soil profile show high organic matter content found at depth 10-20 cm (6.86%), 20-30 cm (8.87%) and 30-40 cm (9.65%) respectively. The occurrence of small stream on the surface soil of SL59 contribute to the organic matter in the soil. Small stream flowing through the lick causing the soil to be constantly saturated with water lead to poor aeration and low oxygen. This condition causes low mineralization rate because microorganisms in the soil became inactive or eventually die. Long term exposure to the water saturated soil with low decomposition rate potentially producing high organic matter content (Bot & Benites, 2005). This situation also explained the soil condition in SL56 where a spring existed in the lick area (Figure 5) thus resulting in higher organic matter (5.28%) in the soil.

Generally, the salt lick soil and control soil show texture variation. This indicates that each lick is different from each other and function differently (Abrahams, 1999). SL20 and SL50 soil texture show clay loam whereas SL56 and SL59 show sandy loam and SL60 shows silt loam. Different percentage of soil particle distribution will affect adsorption. Soil with smaller particle size has high surface area thus greater adsorption capacity (Mandzhieva *et al.,* 2014). Eventhough SL56 and SL59 contain more sand, presence of organic matter and the total percentage of combined value between silt and clay particles ensure enough major elements in the soil (Table 1). This is because fine-textured soils usually have a greater exchange capacity than coarse soils because of a higher proportion of colloids. Most chemical interactions in the soil occur on colloid surfaces because of their charged surfaces (McCauley *et al.,* 2005).

Only two salt licks were selected for profile soil sampling. It is because these two salt lick provide sufficient depth for vertical sampling with approximately 15 cm to 20 cm deep respectively (Table 1). Soil pH value for both salt lick shows small range indicating the soil pH is well buffered (Malik & Haq, 2022). There are no significant changes in pH value between each layer (Table 1). The soil moisture content and organic matter shows fluctuation within depth. This is influenced by the distribution of silt and clay as shown in Table 1 which shows variation across depth (Matus, 2021). SL60 salt lick soil is alkaline (pH 8.32-8.77) with stable pH too. The moisture content and organic matter showing shifting trend with every interval. Low clay percentage in the upper layer (20.20%-22.69%) is the reason for low moisture content as clay has good water retention (Kumari & Mohan, 2021). Decreasing organic matter with depth is due to increasing soil pH as growing condition of microorganism in alkaline environment is poor, resulting low biological oxidation of organic matter (Primavesi, 1984). Both salt lick shows steadily increasing electrical conductivity with increasing depth indicating presence of high concentration of readily available salts (Othaman *et al.,* 2020) such as calcium, potassium, sodium and magnesium as shown in Table 1.

Elemental Concentration

The selected major elements in this study are calcium (Ca), potassium (K), sodium (Na), magnesium (Mg) and phosphorus (P). The concentration of the elements varies for each salt lick. Generally, concentration of phosphorus (P) is the lowest element concentration (47.23 mg/kg – 385.43 mg/kg) found in licks and controlled soils within this study area followed by sodium (Na) (85.83 mg/kg – 529.04 mg/kg). The average elements concentration for SL56 show slightly lower compared to average elements concentration of controlled soils. This result was obtained because one out of three soil samples taken displays low concentration of several elements such as Ca (186.14 mg/kg), Mg (753.21 mg/kg) and P (66.47 mg/kg) which affect the total average concentration. The other two soil samples of SL56 show high concentration of Ca (1559.80 mg/kg), Mg (1786.60 mg/kg) and P (159.48 mg/kg).

SL20, SL50 and SL59 show high concentration of calcium (Ca) whereas SL56 and SL60 are concentrated with magnesium (Mg). In terms of potassium (K), sodium (Na) and phosphorus (P) concentration, SL20 and SL60 were both show greater concentration compared to other salt lick soils (Table 1). Elements concentration in lick SL59 relatively within the same range of the controlled soils average concentration. This phenomenon can be explained by the existence of small stream flowing through the lick. Continuous stream flows cause elements to leach from soils into the water body and be carried away (Lu *et al.*, 2017).

This study shows that the concentrations of calcium were high (1101.92 mg/kg- 11551.64 mg/kg) in the salt lick soils. Parent rocks such as sandstone tends to have acidic pH value thus forming acidic soil (Osman, 2013) due to the presence of high silica which is acidic in nature (Kelesoglu *et al.*, 2012). Existence of calcium in acidic background derived from the decomposition process of animals, microorganism and plants that cause calcium to be mineralized and release back into the soil (Jaiswal *et al.*, 2021). This situation is observed in SL56 and SL59 with acidic soil (pH 5.38 – 6.04) compared to the rest of the licks. Neutral to slightly alkaline lick shows high concentration of calcium. Plant roots also leak minerals, sugars and components like calcium back into the soil (Brunner & Bachafen, 1998). Plants growing on Kulapis Formation beds have the possibilities to absorb calcium from the soil because Kulapis Formation consists of calcareous lithic arenite sandstone (Hutchison, 2005) which is characterized by high concentration of calcium carbonates. This is particularly true in this study where SL20, SL50 and SL60 soils pH values were between those ranges (8.98, 6.96 and 7.53 respectively).

Potassium concentration in SL56 (980.54 mg/kg) and SL59 (767.32 mg/kg) are low in value. Slightly acidic sandy soil contains low potassium ion due to leaching processes (Anderson, 1974) and low potassium bearing mineral such as illite (Mengel *et al.*, 2001). Acidic soil pH displayed by both licks (6.04, 5.38) provide an environment for cation exchange capacity (CEC) competition due to concentration of H^+ is higher and the presence of easily soluble aluminum (Al^{3+}) (Ross & Ketterings, 1995). These two elements will displace other exchangeable cations (K^+) (Rahman *et al.*, 2018) causing the cations move into the soil solution and increase the potential of leaching. In contrast, SL20, SL50 and SL60 exhibited high concentration of potassium (2432.11 mg/kg, 1456.29 mg/kg and 1920.97 mg/kg). This may be due to the existence of illite clay in the soils as illite is the source for potassium (Reitemeier, 1957).

Figure 6. Butterfly observed on the surface soil of salt lick SL59

In this study, the sodium concentrations of the salt lick soils were in range with the controlled soils except for SL20 and SL60 licks. Both of this lick potentially visited by wildlife to nourish their sodium diet. Low concentrations of sodium were observed in SL59 (85.83 mg/kg) but presence of flocks of butterflies on the salt lick soils were noticed (Figure 6). This situation is similar as reported by Sim *et al.,* (2020). This indicates that, the licks play their role as sources of nutrients for wildlife even with low concentration of certain mineral compare to other minerals. Klaus *et al.* (1998) in his research found that the concentration of sodium in lick soils is lower from controlled soil. This phenomenon may arise due to an antagonistic element such as higher calcium concentration tends to exchange sodium in leaching processes (Carrow & Duncan, 2012). Calcium is a divalent cation readily take the place of excess sodium ions which is a monovalent cation occupying the exchange sites of soil colloids. The strength of cation retention by soil particles increases with increasing ion charge and decreasing hydrated ion radius (Bohn *et al.,* 2001). The ease of cation removal from specific colloids has been represented by 'lyotropic series', $Th^{4+} > Fe^{3+} > Al^{3+} > Cu^{2+} > Ba^{2+} > Sr^{2+} > Ca^{2+} > Mg^{2+} > Cs^{+} > Rb^{+} > K^{+} = NH_4^{+} > Li^{+} > Na^{+}$, in the order of decreasing strength of retention (Mitchell and Soga, 2005). The relative extent of adsorption or desorption of ions primarily depend on the valence; for instance, Na^{+} can be easily replaced by Ca^{2+}.

Second most abundant elements observed in the lick soils is magnesium. Among the elements found to be magnesium bearing mineral are chlorite, dolomite, montmorilonite, pyroxene and vermiculite (Scheffer *et al.,* 1966). Thus, weathering of these minerals will enrich the soil with magnesium. Higher amount of magnesium in SL20 (5843.29 mg/kg), SL50 (2501.74 mg/kg) and SL60 (4825.05 mg/kg) is caused by the favorable environment for cation exchange capacity for magnesium take place. Furthermore, the red beds of Kulapis Formation indicate an iron rich source probably influenced by the nearby ophiolite at the northwest of the formation (Hutchison, 2005). Kulapis Formation at the east Bidu-bidu Hills constitutes interbedded pale greyish-red sandstones and chocolate brown mudstone (Newton-Smith, 1967). The Bidu-bidu Hills is the only massive ultrabasic rock found in the study area. The uplifted ophiolites were overlain by serpentinite conglomerates (Newton-Smith, 1967; Hutchison and Tungah, 1991). Thus, this justifies the source of magnesium in Kulapis Formation and supported by the occurrence of mafic mineral observed in the petrographic and mineralogy analysis of this study.

Higher magnesium levels are found in clay soils due to the presence of easily weathered ferromagnesian mineral (Osman, 2013) such as chlorite in the salt lick soil (Figure 8). This explain the higher magnesim concentration in clay texture shown in SL20, SL50 and SL60 samples. Magnesium is a base cation (Havlin, 2005) thus explaining correlation between higher soil pH in SL20 (8.98) and SL60 (7.53) and the exchangeable calcium (8318.60 mg/kg) and magnesium (5843.29 mg/kg) (Yost & Hartemink, 2019). Generally, magnesium shows similar ion exchange with the calcium (Mikkelsen, 2010).

In acidic and sandy soil such as SL56 and SL59, magnesium is easily leach due to higher exchangeable of aluminum and H^{+} in the soil (Metson, 1974; Senbayram *et al.,* 2015). Therefore, higher acidity of soil will lower the magnesium concentration. Coarse soil texture which is high in sand particle percentage increases the removal of magnesium due to the low binding capacity in sand (Senbayram *et al.,* 2015). The presence of flowing stream in SL59 also lead to the lower concentration of magnesium in the lick. Water will cause dilution of elements concentration in the area and flowing river has the potential to bring ions out of the salt lick areas through the leaching process (Lu *et al.,* 2017) further influencing the low concentration of elements in the soil.

As the least concentration observed in the soil, phosphorus is an element that is directly affected by pH. In acidic condition, phosphate ion tend to react quickly with aluminum and iron to form less soluble salt whereas in alkaline condition, phosphate ion react rapidly with calcium and magnesium to form less soluble compound (Jensen, 2010). Neutral soils (SL50) provide conducive environment for phosphorus availability. Alkaline soils (SL20 and SL60) are rich in Ca^{2+} and Mg^{2+} which adsorbs phosphorus and precipitate (Prasad & Chackraborty, 2019). For instance, the precipitation of calcium phosphate occurs when the calcium and phosphorus sources interact at increasing pH of the medium (Avramenko *et al.,* 2023).

Element concentration for soil profile analysis shows that generally all the elements for both soil profile in SL59 and SL60 increasing as the depth increase (Table 1). Exception for calcium where the concentration fluctuates and also potassium for SL60. Nutrient leaching such as magnesium (Mengel *et al.,* 2001) occurs downward soil profile following the movement of water (Lehmann & Schroth, 2002) thus supporting the finding of this study where nutrient concentration is higher in the subsurface soil compare to the surface soil (Table 1).

Table 2 shows the concentration for water samples. Generally, controlled water samples show less mineral content compared to lick's water. Phosphorus is undetectable in both controlled and river. The amount of phosphorus in lick's water sample are too low (0.01 mg/l – 0.03 mg/l). Obviously, average concentration of calcium is relatively high in lick's water (1566.10 mg/kg). The high average concentrations of calcium were also recorded in Rawog river (952.07 mg/kg) and Sg. 50 river (1081.93 mg/kg). Both rivers are located away from the salt lick areas, suggesting the contribution of rich calcium bedrocks to the calcium concentration in the water. According to Otobo (1995) where the concentration and relative abundance of ions in river waters (that is, its chemical composition) is highly variable and depends mainly on the nature of the bedrock, precipitation and evaporation–crystallization processes. This demonstrated that the Kulapis Formation beds as one of the sources of calcium in the study area as calcium leached from the weathering processess.

Apart from calcium, sodium concentration is also high in lick's water sample (568.45 mg/l – 2554.63 mg/l) implying that the elements are leached from the soil into water body. High amount of sodium in the water proposing that wildlife visit the licks for water intake rich in sodium. Exception for SL20 where the amount of potassium (571.68 mg/kg) and magnesium (771.98 mg/kg) are rather high compared to other licks indicating leaching process occurs rapidly in the area.

Petrography and Mineralogy

Three sandstones and two mudstones were collected for petrography analysis. A sandstone sample was collected from the outcrop found in SL59 area and 2 rock samples (a sandstone and a mudstone) were collected in the vicinity of salt lick SL60 area. The sandstones varies from fine to coarse grained. The grains are rounded to subrounded, are well to moderately sorted (Figure 7a and 7b). The matrix percentage is less than 10% represented by brownish colour observed under the microscope. The petrography of mudstone analysis shows that the mudstone is made up of very fine grained minerals and clay minerals as matrix (Figure 7c). Chlorite was also present in the mudstone based on its greenish colour (Figure 7d).

Table 2. Chemical properties of water sample (average values) of licks, control and river nearby

Sample	Concentration (mg/L)				
	Ca	K	Na	Mg	P
SL20 (n=2)	2715.39 ± 1857.50	571.68 ± 4.50	250.44 ± 656.70	771.98 ± 415.44	bdl
SL50 (n=1)	3074.25	9.29	2554.63	10.32	0.01
SL56 (n=1)	1855.25	5.35	568.45	6.45	0.03
SL59 (n=2)	637.67 ± 39.27	7.19 ± 0.00	572.35 ± 3.59	3.98 ± 0.00	bdl
Controls (n=6)	361.20 ± 639.33	2.05 ± 0.81	4.38 ± 0.87	5.00 ± 2.23	bdl
Sg. 50 (n=2)	1081.93 ± 14.99	1.96 ± 0.02	7.40 ± 0.08	4.48 ± 0.01	bdl
Rawog river (n=3)	952.07 ± 174.57	3.76 ± 0.75	10.01 ± 0.04	4.09 ± 0.09	bdl

Bdl: below detection limit

Plagioclase was also detected in very small amount and heavily weathered (Figure 7e) as well as microcline feldspar (Figure 7f) in sandstone. Authigenic mineral such as muscovite and chlorite are also observed in the sample as an elongated sheet like structure (Figure 7g). The muscovite grain changes in direction due to the strong movement of quartz grain (Worden & Burley, 2003).

Figure 8 shows the scanning electron microscopy (SEM) results conducted on salt lick soil samples for the identification of major minerals or clays, their morphology and structures. The minerals identified that made up the lick soil composition are chlorite, illite and smectite. It is clearly visible that smectites are abundant in lick soils, showing an Okal leaf structure (Figure 8a) (Abu El-Ezz *et al.*, 2012). The individual grain is poorly defined due to diffuse outlines and curled edges forming flower like structure (Abu El-Ezz *et al.*, 2012). It can be regarded as aggregates with foliated and lamellar structure as a result of the expulsion of water and gas during compaction and oxidation of organic matter (Keller, 1985). As observed from the thin section, the feldspar grain had undergone intense weathering. Dissolution of alkali feldspar will produce aluminum ion and silica in aqueous form (Huggett, 2005). According to Huggett (2005), dissolution of K feldspar will yield Al^{3+} and K^+ which will react with smectite to form illite-smectite and ultimately illite:

$$\text{Smectite} + Al^{3+} + K^+ \rightarrow \text{Illite} + Si^{4+} + Fe^{2+} + Na^+ + Mg^{2+} \quad \textbf{Eq.(1)}$$

Potassium ion for the illitization was supplied mainly from the alteration of K feldspar within the sandstone and from mica within the shales (Kumar *et al.,* 2016). Abundance of potassium can be seen from the elemental concentration analysis. Both aluminium and potassium ions will react with smectite to form illite-smectite and eventually illite in the later. This process is known as illitization.

Illitization occurs in sediments enriched in K-feldspar (Worden & Morad, 2000). Illite occurs with different morphologies according to the potassium supersaturation during precipitation (Weibel *et al.,* 2020). The pattern of illite-smectite shown in Figure 8a appear as crooked scaly and partly foliated. In contrast to Figure 8b where the illite shows fibrous structure indicating of rapid growth during burial (Mullin, 2001). The formation of fibrous illite requires higher thermal exposures compare to that of the illite formation by smectite illitization (Stroker & Harris, 2009). Thus, the existence of fibrous illite in this study proves that Kulapis Formation was exposed to high thermal environment during burial.

Chlorite was also found in the salt lick soil samples. The chlorite minerals occur as poorly developed plates with irregular outlines or ragged edges and it shapes shows a high magnesium type chlorite (Hillier, 1994) (Figure 8c). Chlorite also exhibits edge to face, face-to-face (Figure 8d) and edge-to-edge contacts (Wilson *et al.*, 2014). According to Wilson *et al.* (2014) less developed chlorite crystal structures indicate authigenic origin. Smectite transforms into chlorite in alkaline condition that rich in iron and magnesium ion (Chen *et al.,* 2011). Chloritization is a process where smectite reacts with Fe^{2+}, Mg^{2+} and water to transform into chlorite. According to Chang *et al.* (1986):

$$\text{Smectite (saponite)} + Fe^{2+} + Mg^{2+} + Al^{3}+ H_2O \rightarrow \text{Chlorite} + Na^+ + SiO_2 + H^+ \quad \textbf{Eq.(2)}$$

$$\text{Smectite (saponite)} + H_2O + H^+ \rightarrow \text{Chlorite} + Ca^{2+} + Na^+ + Fe^{2+} + Mg^{2+} + SiO_2 \quad \textbf{Eq.(3)}$$

Chlorite sources include transformation of detrital Fe-rich berthierine, transformation of Mg-rich smectite (Wilson *et al.,* 2014). The specific origin of chlorite controls its composition. Chlorite in marine sandstones is origined from berthierine source, whereas chlorite from the continental sandstones originated from smectite (Berger *et al.,* 2009; Worden *et al.,* 2020). Following the findings of SEM analysis, it is confirmed that the chlorite found in this study is originated from smectite.

The clay minerals composition in soil suggest that made up soil shows that the salt lick soils supply a good amount of nutrients. The dissolution of smectite contributes calcium, sodium, magnesium and silica into the soils (Metz *et al.,* 2005). Illite is in potassium (Barre *et al.,* 2007) whereas chlorite contains abundant iron and magnesium (Deer *et al.,* 2013).

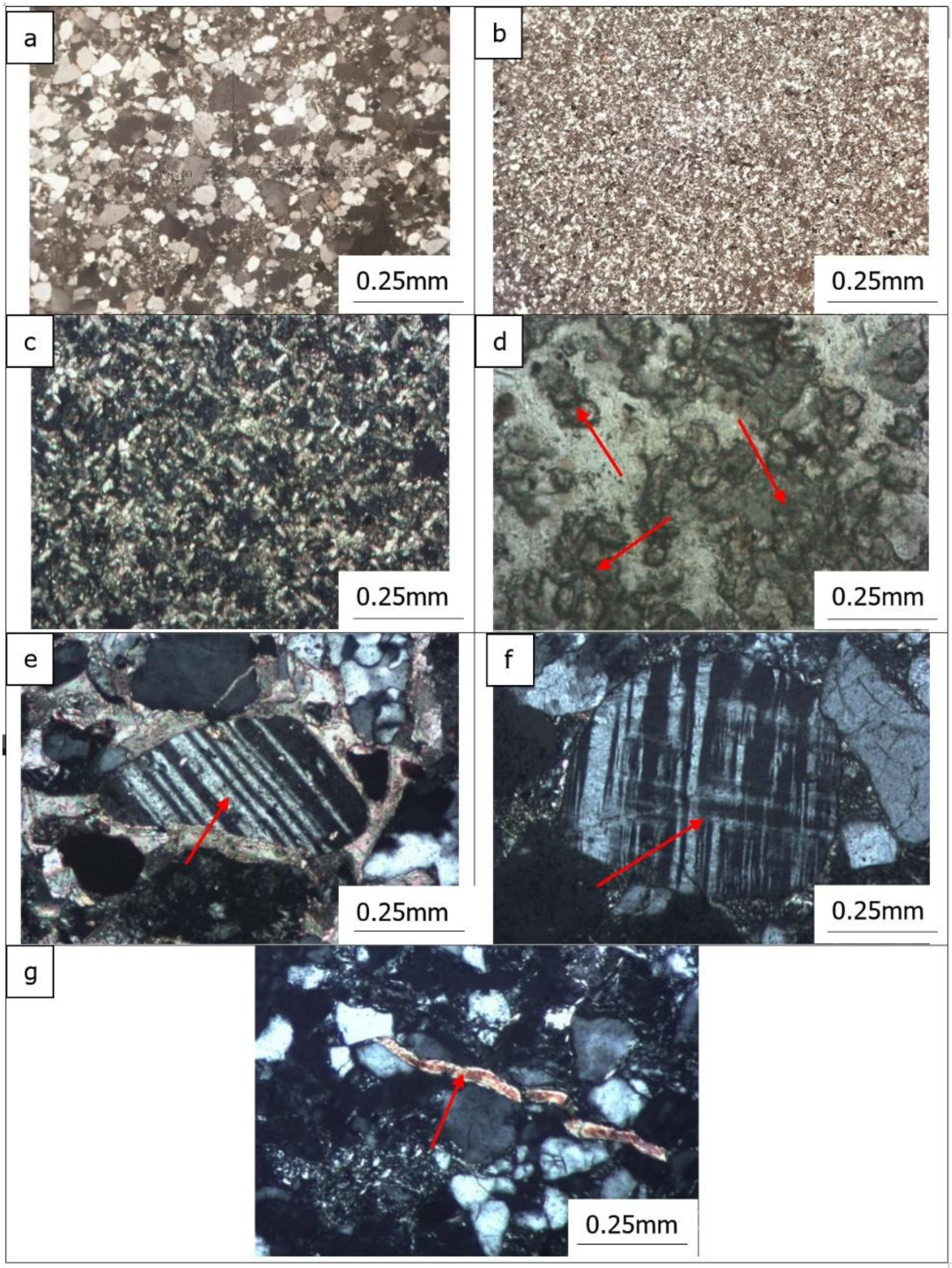

Figure 7. (a) Coarse grain sandstone. (b) Fine grained sandstone. (c) Fine-grained mudstone. (d) Greenish chlorite mineral (red arrows). (e) Heavily weathered plagioclase feldspar (red arrow). (f) Microcline feldspar (red arrow). (g) Muscovite mineral shows elongated shape (red arrow)

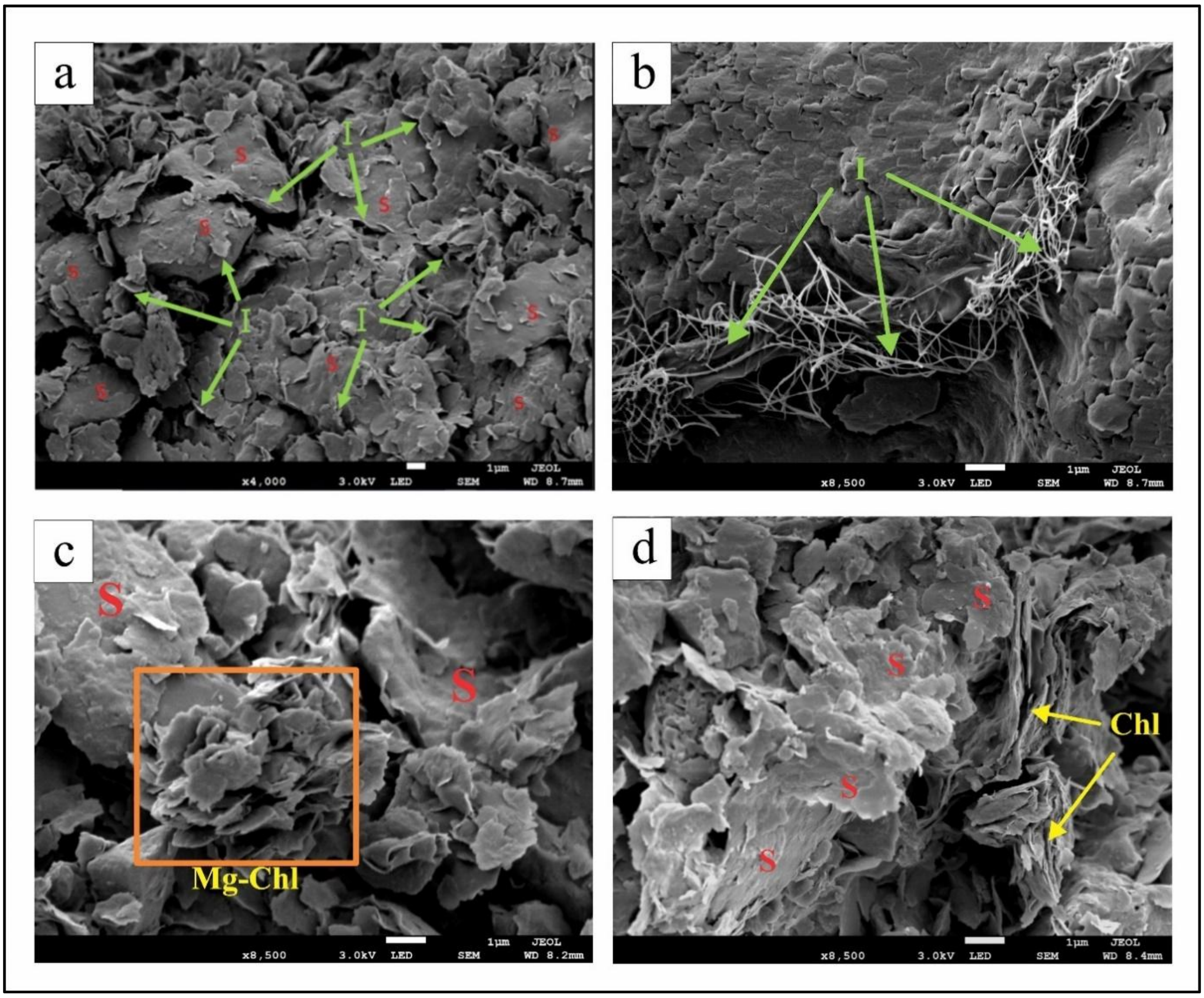

Figure 8. (a) Smectite showing curved leaf like structure with illite appear crooked scaly and foliated partly. (b) Fibrous illite. (c) Less developed Mg-rich chlorite indicates authigenic chlorite (orange box). (d) Chlorite mineral shows parallel structure surrounded by smectite. (Chl= chlorite; I= Illite; S= smectite)

CONCLUSION

In summary, salt lick soil shows slightly acidic to alkaline, high moisture content, high organic matter and high electrical conductivity values compared to control soils. Soil texture for salt lick soils best describe as loam. All lick soils and water samples express high concentration of essential mineral such as calcium, potassium, sodium, magnesium and phosphorus compared to control sites. Although overall elements concentration is slightly low in SL56 and SL59 samples, these two licks served their purpose as nutrient source as sodium seeking species were spotted at the sites. The presence of flowing river in the latter lick also possibly the reason for wildlife visitation. Types of clay such as chlorite, illite, and smectite further contribute to the presence and concentration of the elements in the salt lick of this area. Comparison with the published report in Deramakot Forest Reserve, Kulapis Formation in the present study shows a wider range of element concentration. The findings give insight on the variation of element concentration in salt lick soils of the same rock formation. Therefore, this study serves as a geochemical baseline data on the distribution of elements concentration of salt lick soils especially in Kulapis Formation.

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