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Geology and Geochemistry of the Sub-Basalt Tin Mineralization in Wereng, Riyom, Part of the Naraguta SE Sheet 168

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ABSTRACT

The study area is situated within the Jos-Bukuru Younger Granite Complex and, and overlies the Basement Complex of North Central Nigeria. It is bounded between latitudes 8º 41' 00''N - 8º 50' 00'' and Longitudes 9º30' 00'' - 9º 40' 00''E which is part of the Naraguta SE Sheet 168. Detailed studies shows how the widespread Tertiary-Quaternary Basaltic Lava flow that earlier submerged concentrated Tin deposits along ancient river/stream channels have suffered great deal of chemical alteration (continuous oxidation an d leaching), thereby resulting into various grades of Basaltic saprolite bands/layers of varying thicknesses within the study area whose boundaries are geochemically controlled and not lithological, they include; the Iron Caps atop, the reddish-brown saprolite layer, the reddiSub-Basaltsh-brown+intercalations of Kaolin layer, the yellow saprolite layer, and finally the Kaolin layer which directly overlies the Tin bearing sediment layer along ancient river/stream beds. The saprolite laterite constitute an overburden thickness of 35-40m to the (2-2.5m thick) Tin deposit bearing sediments. Geochemical and petrographic investigation reveals that the mineralized greisens of Biotite (Tin) Granite and the Basement rock (Gneiss) are petrogenetic to the origin of the Tin deposits concentrated within the ancient river/stream beds. This studies also shows the prolificness of the Sub-Basalt Tin mineralization of (40,000-62,000ppm per every 1.5kg of sediments sampled) within the area, as well as Zircon, Kaolin and Niobium. Integrating information from concentration trend of Tin obtained from Pit samples, aeromagnetic data which shows the heavy metals concentration trend of the study area, and a careful studies of modern drainage patterns gives a NE-SW orientation pattern which suggests the paleo/ancient river/stream direction, serving as a very useful exploration tool of utmost importance. Occurrences of Nodular Basalts in dyke form which have remained stable and unaltered throughout the study area.

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Introduction

Tertiary- Quaternary Volcanics (characterized by Basaltic suits) directly overlies the Basement rocks and/or cross-cut both the Older and Younger Granitic bodies. (Macleod et al., 1971) identified based on morphology, age of emplacement and petrography two basic types of these basalts within the area; the Older and the Newer Basalts - formed during the Tertiary and Quaternary periods respectively.

Tertiary to Quaternary episodes of volcanism was characteristically widespread and well developed on the Jos Plateau area, with the eruption of the basaltic lava flows submerging the alluvial Tin deposits bearing sediments along the courses of former ancient streams/ river systems or erosional surfaces that cut across the rock basement (Anaba, 1982, U.A.Lar, 2003). Erosion surface represents episodes of sufficient duration to cause heavy mineral concentration (as deep lead deposits).

Partly decomposed Basaltic boulders, plugs or dome-like outcrops represents the Older Basalts. They are very visible from the Wereng Valley Southward of Jos extending to Rukuba area, Ganawuri, Southern Ropp, Mbar and Mangu axes. The different grades of lateritized Basalts represents the product of chemical (alteration) weathering of mainly the Older Tertiary Basalts (Macleod et al., 1971).

The study area is situated within the Jos-Bukuru Younger Granite Complex and, and overlies the Basement Complex of North Central Nigeria. It is bounded between latitudes 8º 41' 00''N - 8º 50' 00'' and Longitudes 9º30' 00'' - 9º 40' 00''E which is part of the Naraguta SE Sheet 168, covering a total of 85km^2 on a scale of 1:25,000. The area is located in Wereng and Riyom, Riyom LGA of Plateau State, and is accessible via the Riyom-Abuja Road, then through minor roads and footpaths that crisscross the area.

To study and characterize deep lead deposits (as in the case of the Sub-Basalt Tin), the nature of occurrence, size and thickness of the overlying materials (saprolite cover) must be astutely established. Similarly, establishing and the understanding the direction of flow of the ancient river stream where the weathered greisens were deposited is of cardinal importance. Wereng area have been understudied despite having a long traceable mining history that predates as far back as 1900s, little or no studies have been done to ascertain degree of chemical weathering on the Basalts which have resulted into the various lateritic/clayish bands. Detailed geologic records and mineralization that sufficiently provides information which defines typically the Tin deposits and their general assessments are not available, even though German and British tunnels exist. Of cardinal importance, the type and nature, evolution, thickness of the overlying basaltic weathered (Saprolites) bands and the depth of burial have not been adequately established.

The research is aimed primarily to ascertain detailed geologic and geochemical information which defines and characterizes the various Bands/ layers of the highly altered/weathered Basalt (Saprolites) overlying the Tin-rich bearing sediments within the course of ancient river channels as well as geochemical investigation of the tin bearing sediments in the study location, and can be achieved through the following objectives:

- Develop a model for the various bands (geochemical boundaries) and thicknesses of the weathered Basaltic cover.
- Establish the nature and other types of mineralization within the different lateritic bands/layers
- Define and Characterize Kaolinisation of basaltic origin, grade and the economic viability within the area.
- Geochemical characterization and interpretations of several Pits and Tunnel data to establish the abundance and prolificness of the Sub-Basalt Tin mineralization
- The utilization and treatment of pits data, aeromagnetic data of Wereng areas as well as careful studies/

examination of modern drainage patterns, valleys, around Wereng areas, so as to obtain clues about the historical flow direction of the ancient river/stream and valleys.

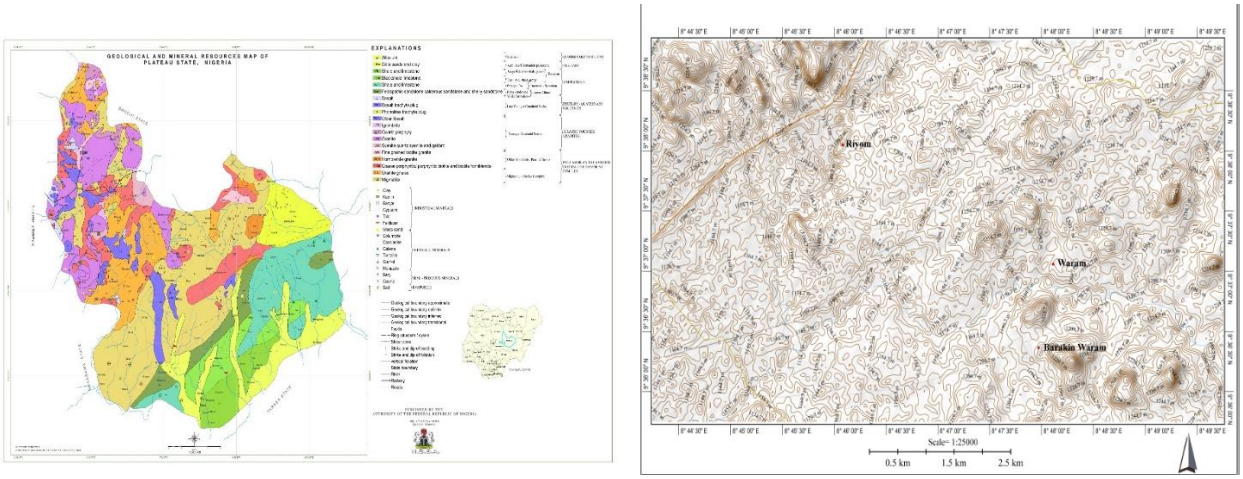


Fig.1: Location Map of the Study Area

The area has distinct Basaltic saprolitic hills represented by either volcanic cones or volcanic domes, having an average undulating relief 1250m Above Mean Sea Level (MSL) within the central and NE portion of the area. The Northern portion characterized by the Jurassic Younger Granites has an average relief of 1300m Above Mean Sea level (MSL) (Fig.2)

The collective system of drains and runoffs within the area is being facilitated by rivers which mostly take their source from the Jos highlands. Drainage pattern envisage within this area is morphologically controlled (Fig. 3).

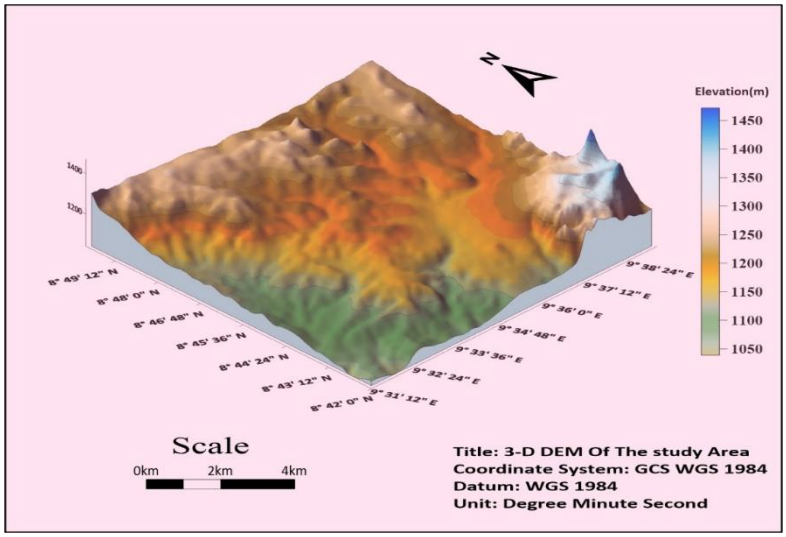


Figure 2: 3D Digital Elevation Model (DEM) of the Study Area

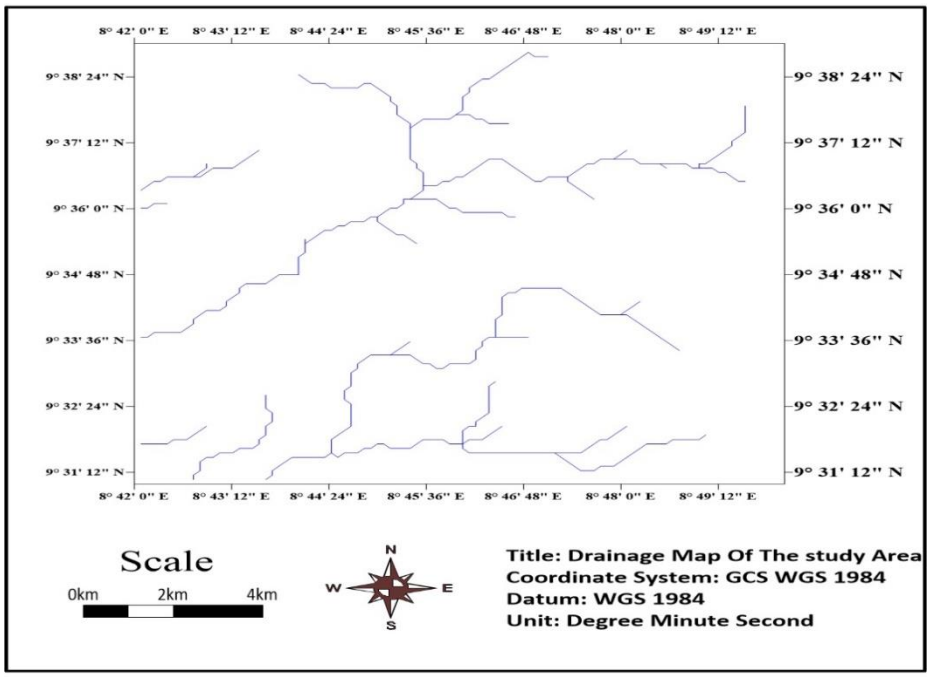


Figure 3: Drainage Pattern of the Study Area

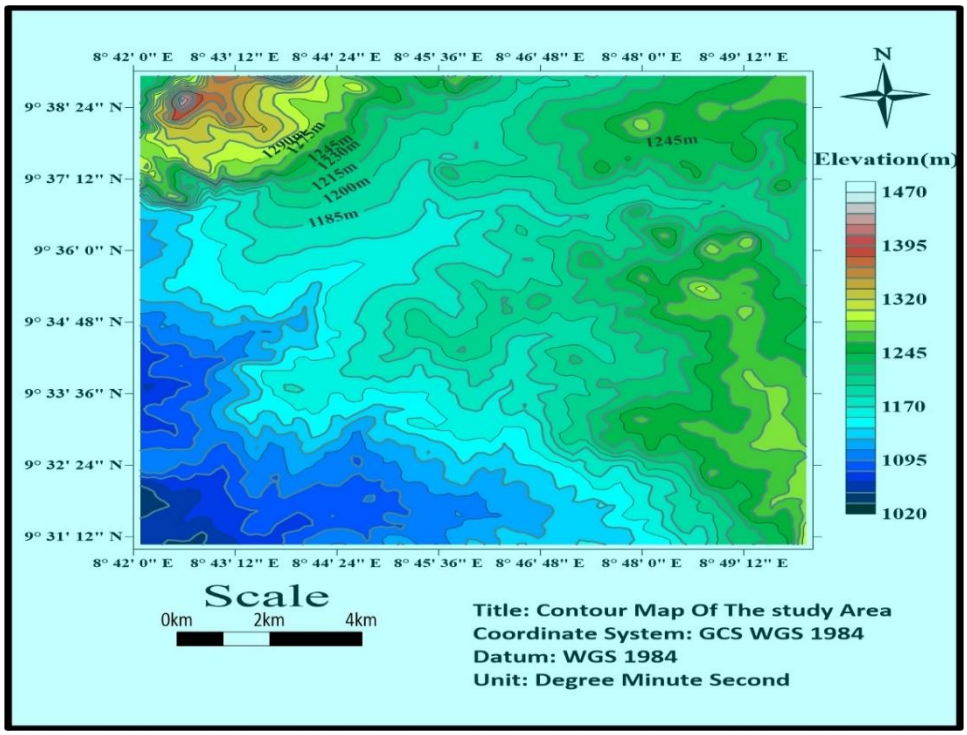


Figure 4: Relief Map of the Study Area

OVERVIEW OF THE GEOLOGY OF TERTIARY-QUATENARY BASALTS

These are characterized by a group of Basaltic suits which directly overlies the pre-existing Basemen rocks and/or cross-cut both the Older and Younger Granite complexes. Basaltic lava plateaus, Trachyte plugs and domes, large central volcanoes and small Basalt cinder cones with thin flows are all found among the more southerly manifestations of the Cenozoic Volcanism in West Africa (Wright, 1985). Areas of Basement dooming include the Jos Plateau, Southeast of the Benue Trough, with probably still greater uplifts; and the Adamawa Highlands. Situated within the Zambuk Ridge of the Northern Benue Trough, are the Flood Basalts of the Biu Plateau, and the smaller Longuda Plateau lies near the bifurcation of the Northern Benue Trough, which has been identified as a possible secondary triple junction (Wright 1985).

Two main types of these Basalts have been identified based on their age of emplacement, morphology and petrography (Macleod et al., 1971). These are; the Older Basalts- formed during the Tertiary period and the Newer Basalts emplaced during the Quaternary times and have somewhat been subjected to relative degrees of weathering and lateritization.

On the Jos Plateau, the earliest Basaltic lavas were widespread and more or less continues of the somewhat enigmatic Fluvio- Volcanic Series, with eruptions of basaltic lava flows covering alluvial Tin bearing sediments along the course of ancient river streams/rivers and valleys



Fig.5: Cretaceous –Tertiary Igneous activities generally located within the Benue Trough of Nigeria (Wright 1985)

The older Basalts are elative highly weathered Basaltic rocks said to be thoeliitic (containing little or no Olivine). They are of the Tertiary age (formed during the combine geologic periods of Neogene and Palaeogene from about 66-5 Ma ago) (Macleod, 1971). (Bowden, 1978) suggested that some of the Older Basalts may be as young as approximately 11Ma, but it's probable that their activities were widespread over a long period of time. They are, in general, completely decomposed Saprolites, usually to creamy-coloured, plastic clay-like materials. The invasion of the Older Basalts possesses great deterrent to the prospecting of the Tin deposits within the ancient valleys, because of the difficulty in interpreting the original stream pattern. (S.G. Chollom, 2001)

Newer Basalts are much fresher and younger 'Alkali' or Olivine Basalts, which differ in composition from the Older Basalt series, geologically very young and are largely Quaternary age (2Ma- recent times). (Burke and Durotoye, 1970). In Jos Plateau, most of the Newer Basalts are chemically weathered or decomposed. The foreseeable exhaustion of other alluvial reserves, with little prospect of important argumentation by new exploration outside the Basalt-covered areas, has motivated consideration given to the possible mineral potential of the areas covered by the Newer Basalts. There are many of such areas in the Jos Plateau. The majority of the prospective areas are known to be cover major ancient river / erosional valleys. These valleys have however been highly understudied. More so, where

the valleys have been buried in its entirety, prospecting or geological evidence of the possible tenor of mineralization beneath the Basalt is almost completely unavailable. The Sub-Basalt Tin deposits are quite simply, normal alluvial deposits that have subsequently been flooded by and underlain by the episodes of Basaltic flows. Most of the ore bodies are associated with channelized mineralization contained in ancient river channel sands and gravels underlying the Basement. The total thickness of the Pre-Basalt sediments is variable, but in Sabon Gida area, SW of Jos, it attains depth of about 80ft (26m) thick or more. The focus of the Basalt flows may have given rise to visible volcanic cones (for example, the Miango and Vom Basalt), but elsewhere, the lavas may have probably erupted from fissure flows (for example the N'gell Basalt

REVIEW OF SUB-BASALT TIN DEPOSITS JOS PLATEAU

When basic magmas of low viscosity swell up along pre-existing fissures from a batholith, the landscape could be completely buried under enormous sheets of the fluid lava. This process is called Basalt flow. During the Tertiary period, Basaltic lava flows covered parts of the Biu, the Jos, and the Lunguda Plateaus (all in the Northern Nigeria) to fill the eroded valleys. When the lava had solidified in the Jos Plateau valleys, it was more resistant to erosion than the Granites in-between. The younger Granite ring complexes were eroded more quickly, leaving the Basalt flows as resistant hills. The Basalts eventually weathered forming deep clay regoliths or saprolits, leaving the former valley Basalts standing as lateritized flat-topped hills. Later flows of Newer Basalts (0.2 Ma-recent) also buried parts of Jos Plateau. Results obtained from several studies on the Sub-Basalt Tin indicates that there is a very high potentials of Tin beneath the Basaltic lava flow yet untapped (Anaba, 1982, Macleod et al., 1971, U.A Lar, 2003).

Methodology

Detailed geologic mapping of the area was carried out on a scale of 1:25,000, to understand the different Saprolitic Bands/layers or horizons, which are product of chemical weathering in the area, their nature, and thicknesses and to establish possible mineralization within each of these bands. A detailed systematic method of mapping which include; traversing from one Ridges/Hills and outcrop to the other (about 20) taking notes of the different bands/layers across each Saprolite hill, keen attention was given to dug pits and tunnels-measuring their depths and sampling from them. Digital/mobile camera was employed for taking photos features observed in the field.

Over 40 samples were collected from the field, twenty-six (26) representative samples (laterite bands/layers, rock units and pits/tunnel) were carefully collected and taken for petrographic and geochemical analysis. Whole rock geochemistry using EDXRF Analytical method was employed for the analysis, this was carried out at the Geochemistry Laboratory, Department of Geology, Gombe State University, Gombe, and in the Nigerian Geological Survey Agency, Kaduna. Several geochemical plots such as Hacker variation, Spider diagram, feldspar plot, tectonic discrimination, AFM diagram plots were generated from the geochemical results using GCDkits and Petrograph software for the geochemical studies. The data were compared with results of the fieldwork, presented, and discussed below.

RESULTS AND DISCISSION

Field Relation

The Basalts within the study area have experience extensive rate of chemical (alteration) weathering, resulting into various grades of saprolitic bands/profiles, which are geochemically bounded. These bands/layers include: The Iron cap layer, reddish-brown laterite layer, reddish-brown+ intercalated Kaolin, the yellow Laterite layer and the Kaolin layer at the bottom sitting directly on the Tin bearing sediments layer lying along the ancient river/stream beds. The E-W trending Nodular Basalts have remained stably unaltered throughout the study area I the form of dykes. Biotite Granite are within the N-E flank of the study area, while the basement is mainly exposed along river and stream channels.

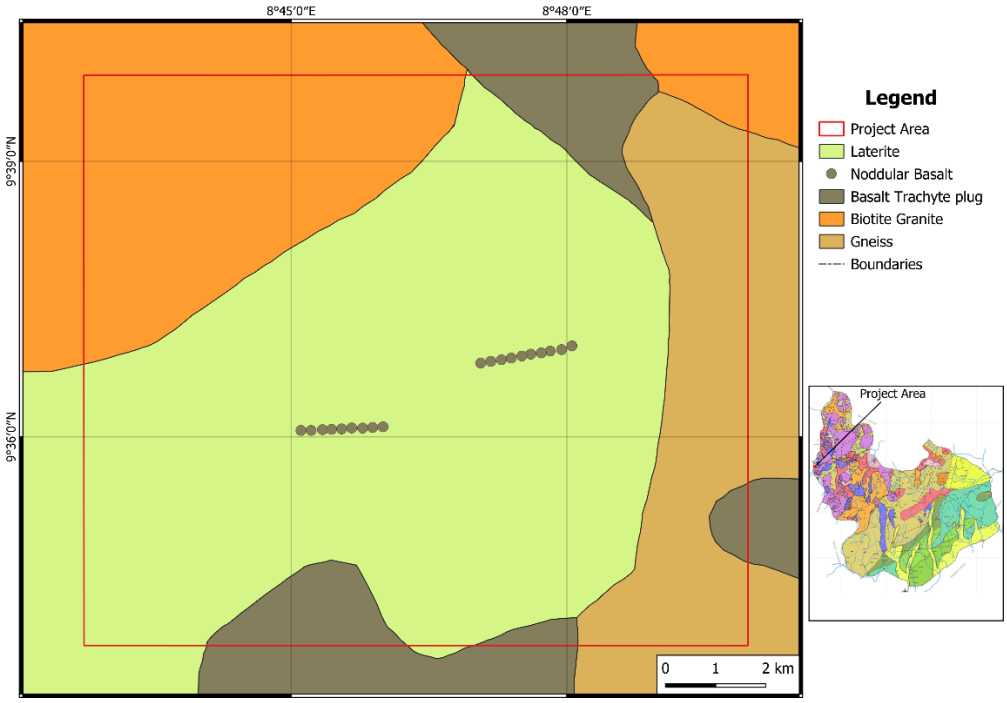


Fig. 6: Geologic Map of the Study Area

Iron Capping's Layer

Chemical oxidation of iron oxides within the Basalts and leached to the surface resulted to the formation of the iron capping during chemical weathering. Iron cappings, which are sometimes referred to as ferricretes are hardened layer of the laterites resulting from soil particles being cemented by Iron Oxides constitutes the first band/layer of the Saprolitic geochemical profile which are hard Ironpan or metallic aggregates. The iron cappings are usually dark-brown coloured, with thickness range of 3-8m in places

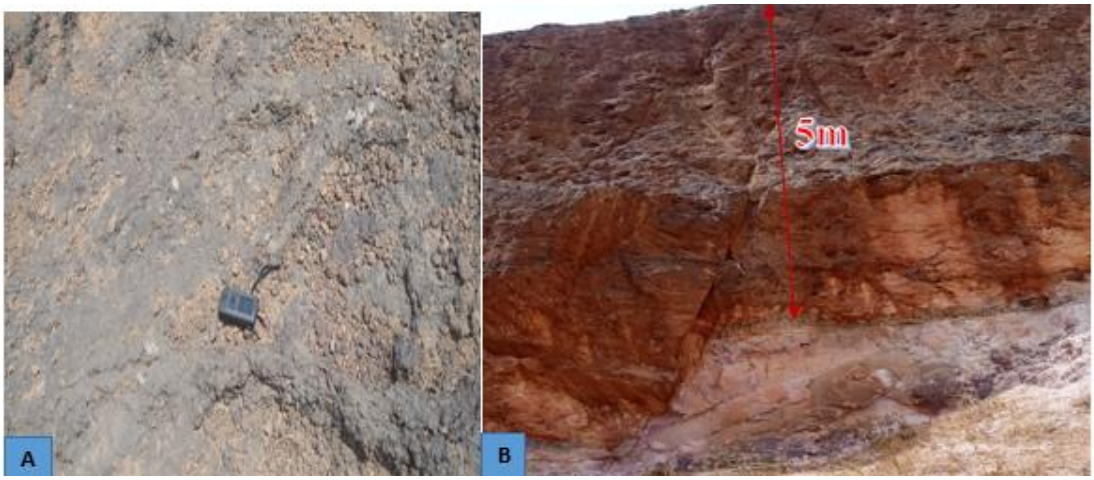


Plate 1: Iron Capping top View **(A)** which forms the first layer/Band measuring 5m **(B)**

Reddish-Brown Laterite Layer/Band

This is a leteritised layer formed as a result of chemical weathering of the basalts, directly underlying the Iron Cappings. It is majorly reddish-brown colouration, but could be Purplish in some areas. This layer's / profile's geochemical boundary has a thickness of 6-12m. Exposures of this layer is a result of erosion of some parts of the ridges, or along excavated areas.

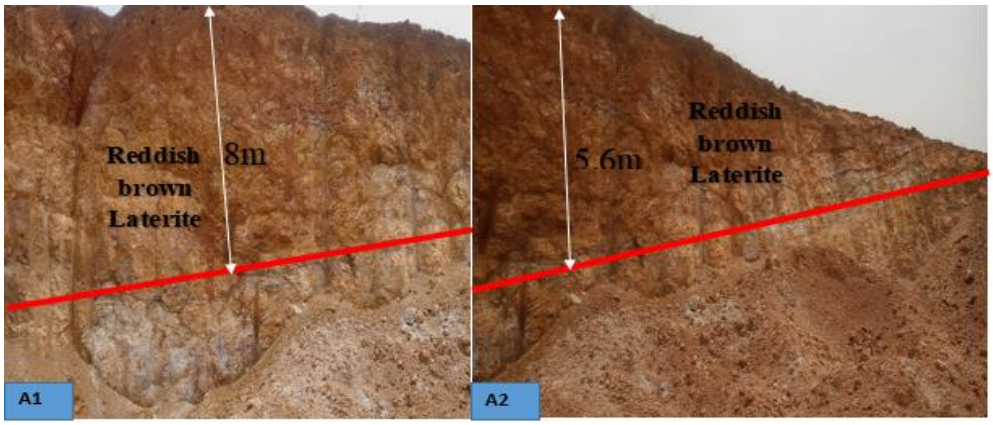


Plate 2: Reddish Brown (A1 and A2) Laterite Layer exposed at mine site

Reddish-Brown Intercalated with Kaolin Layer/Band

This layer has experienced a greater degree of weathering than the first two. The intercalations of Kaolin within the reddish-brown laterite indicates alternate rise and fall in water level within the system prior to the chemical weathering period. Minerals of Kaolin within the solution leached/seeps into the laterites and became part of it. This layer/band has a corresponding thickness range of 3-7m. This layer too is been exposed within mined areas.

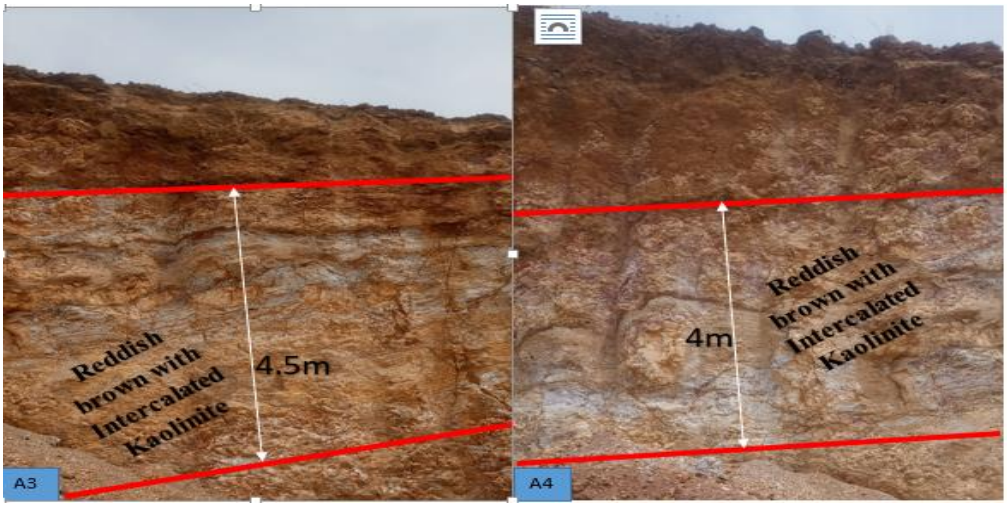


Plate 3: Reddish Brown with Intercalated Kaolin (A3and A4) Layer Yellow Laterite Layer/Band

Weathering action of this layer is more than in the previous layers. The yellowish disposition of this band/layer is a result of remnants of oxidized Iron (Fe) within the system and an elevated water level prior to the time of formation of this band. Its thickness ranges from 3-6m in places. Sometimes this layer is absent in places (replaced with intercalated Kaolin and Brown laterite, or the Kaolin levels directly). As seen in the diagram below (A5 and A6), this layer is more reduced overburden to the Tin bearing sediment zone, hence, local pits are dug to reach the Tin deposits



Plate 4: Field View of Yellow Laterite (A5 and A6) Layer/Band

KAOLIN LAYER/BAND

Kaolinisation which is the replacement or alteration of alkali feldspar and Micas into the clay mineral Kaolin in the presence of slightly acidic solutions as a result of weathering or hydrothermal alteration. This profile shows the greatest level of chemical weathering of the Basalts. Kaolin forms at the base of the profile overlying the Tin ore bearing sediment lying on the ancient stream bed. Two varieties are seen within the study area- the white Kaolin and the Yellow Kaolin (presence of elevated water level during formation). Kaoline layer has a thickness range of 4-15m in places.

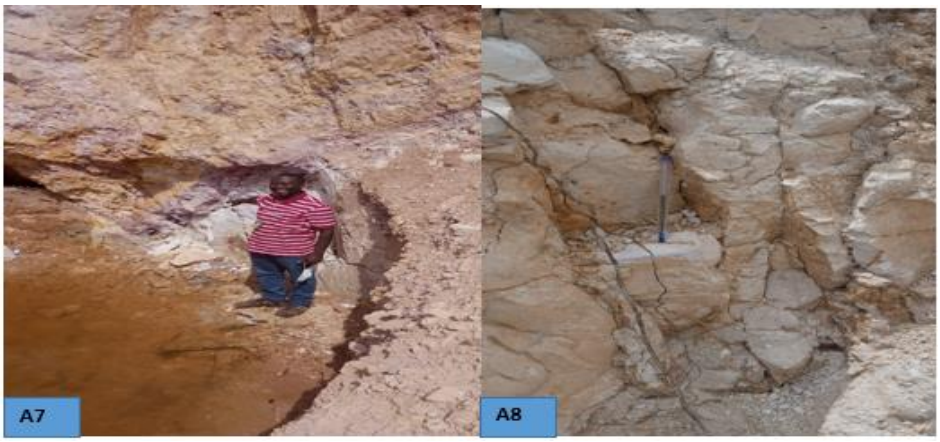


Plate 5: Photo of Field Occurrence of Kaolin in Wereng



Plate 6: Photo of hand specimen of White Kaolin (WK), and Yellow Kaolinit (YK)

TIN ORE BEARING SEDIMENTS LAYER/ BAND

This layer contains the weathered and eroded materials of the Tin Granites that were deposited within the courses of ancient river/stream channels which are enriched in Tin ore as deep lead deposits. Studies have shown that about 95% of the Tin on the Jos Plateau is derived from the Biotite Granites of the Younger Granite ring complexes, while the Basement complex could be responsible for the remaining 5% (Pastor and Ogezi, 1986; U.A Lar, 2003). This layer however does not form part of the Basalt Saprolite profile. (S.G.Chollom 2001, Mallo, 2007) posited that 95% of the placer Tin deposit (6m to 12m thick in places) have remained untapped in ancient river channels overlain by the Tertiary- Quaternary Basaltic lava flows, forming an overburden thickness of 27-35m . This layer is however the major target by explorationists in the quest to harness the great potentials of Cassiterite deposits that have been buried by these episodes of Basaltic lavas. In Wereng, the thickness of this layer ranges from 2.5-3m in places. Access to this level is possible through drilled/dug pits measuring about 35-40m deep from the surface.



Plate 7: Photo (PTK1 and PT2) of a Local Hand dug Pit to access the Tin Bearing Sediment and zone in Wereng Camp Area.

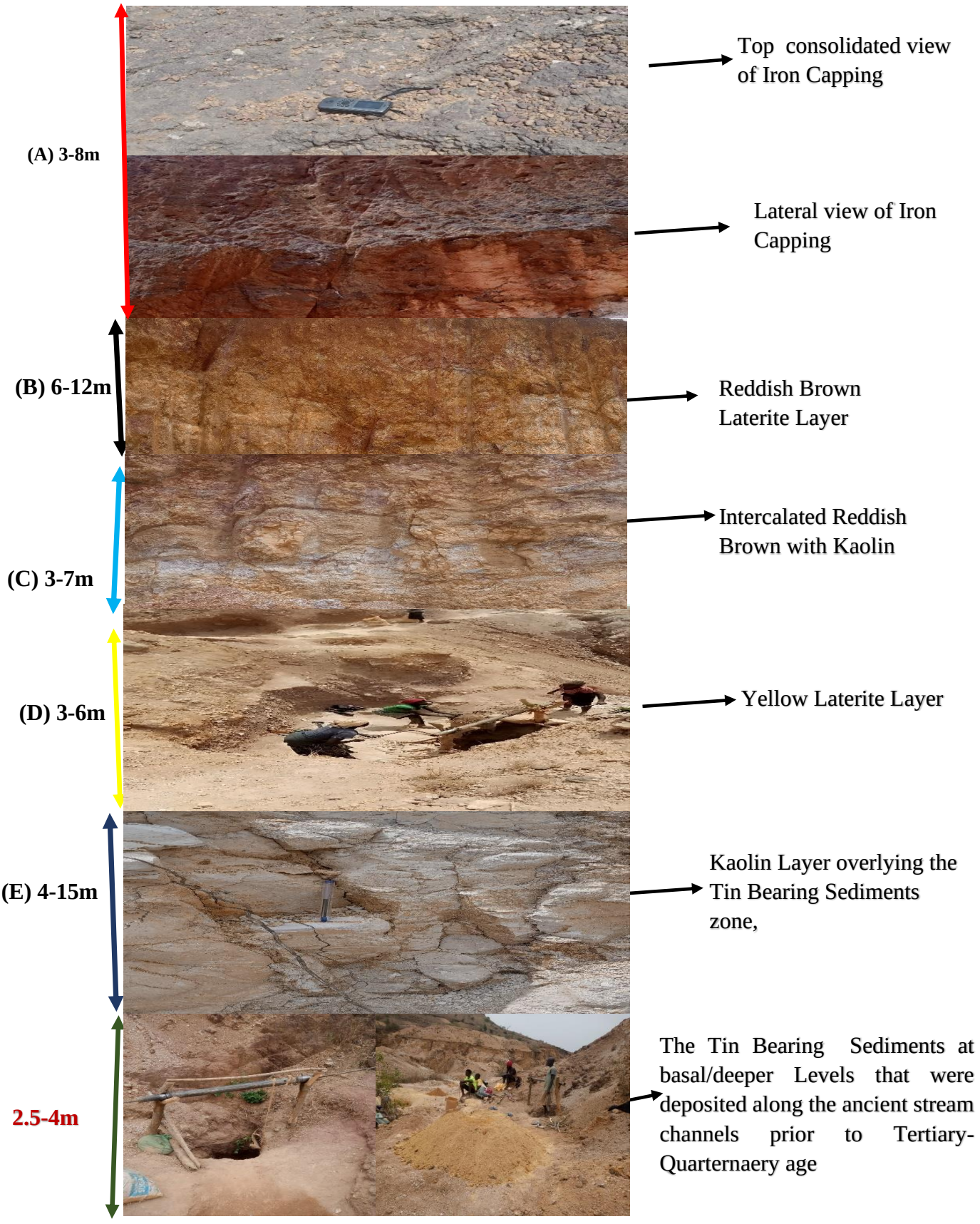


Plate. A Typified Profile of the Weathered Basaltic Saprolite in Wereng Camp Area, Plateau State.

Properties of the Weathered Saprolitic Layers/ Bands overlying the Tin Bearing Sediment.

Table 1: *The table above depicts a total of 5 horizons/layers of weathered Basaltic Saprolite which constitute the overburden (35-40m) to the basal Tin bearing Sediments in ancient river Stream. It also shows the various mineralization within this area with basic minerals such as Tin and Kaolin. Others are, Collumbite, Zircon, Chromite and Silver within some specific bands.*

S/N	Layer Type	Thickness	Properties	Occurrences/ Mineralization
1	Iron Capping Zone	3-8m	Dark-coloured ferricretes of Ironstone, stable and resistant to erosion	Chromite
2	Reddish Brown Laterite	6-12m	Reddish brown coloured, Less consolidated.	Chromite, Silver
3	Reddish Brown with intercalated Kaolin Zone	3-7m	Intercalations of Kaolin patches within this layer is as result of rise and fall level of water within the area as at that time.	Silver, Chromite
4	Yellow Laterite Zone	3-6m	Loosed sands indication advanced level of weathering of the Basalts, elevated water level was present within the layer as at the time of formation.	Silver
5	Kaolin Zone	4-12m	Occurrence of Kaolin, indicating the highest level of weathering of the Basalts.	Kaolin
	Basal Tin Bearing Sediment Zone	2.5-4m	Brownish loosed sand and gravels. Can only be access through pitting or tunneling.	Tin, Collumbite Zircon, Chromite

The basement rocks which are majorly Gneisses are mostly found exposed along streams/river channels with the study area. These rocks are medium-coarse grained and characterized by a layered appearance caused by segregation of ferromagnesian from quartzofeldspathic minerals in discontinuous layers or lenticles. The ferromagnesian are usually Biotite and /or Hornblende.



Plate 8: Photo of Field Exposure of field Exposure of the Basement Rock (Gneiss) (FGN1 and FGN2) and Hand specimen of Gneiss (GNS1) in Wereng.

THE BIOTITE GRANITES

This set of Younger Granite rock is found in the North-Eastern portion of the study area. They have very coarse-grained matrix of both felsic and mafic minerals. This rock type is thought to host the greisens that hosted the Cassiterite ore, which were eventually weathered and deposited within the ancient stream/river channels. Common minerals seen by megascopic check include; Biotite, plagioclase Feldspars, and Hornblende, with a general felsic colour disposition.



Plate 9: Photo of Field (SMK1 and SMK2) and Hand Sample (SMK3) of the Biotite Granite Outcrop around Sambak, NE of Wereng.

THE NODULAR BASALTS

This rock type has remained unaltered throughout the entire area under study. This are thought to be more chemically stable on the surface, or that they the protruded the Basement and the Older Basalts, and were emplace much recently after the newer stream/river courses had been established. The Basaltic nodules occur in the form dykes running E-W within the area. Their occurrence is seen within just few locations, thus beneficial, otherwise it'd have made the exploration and exploitation of the Sub-basalt Tin much more difficult.

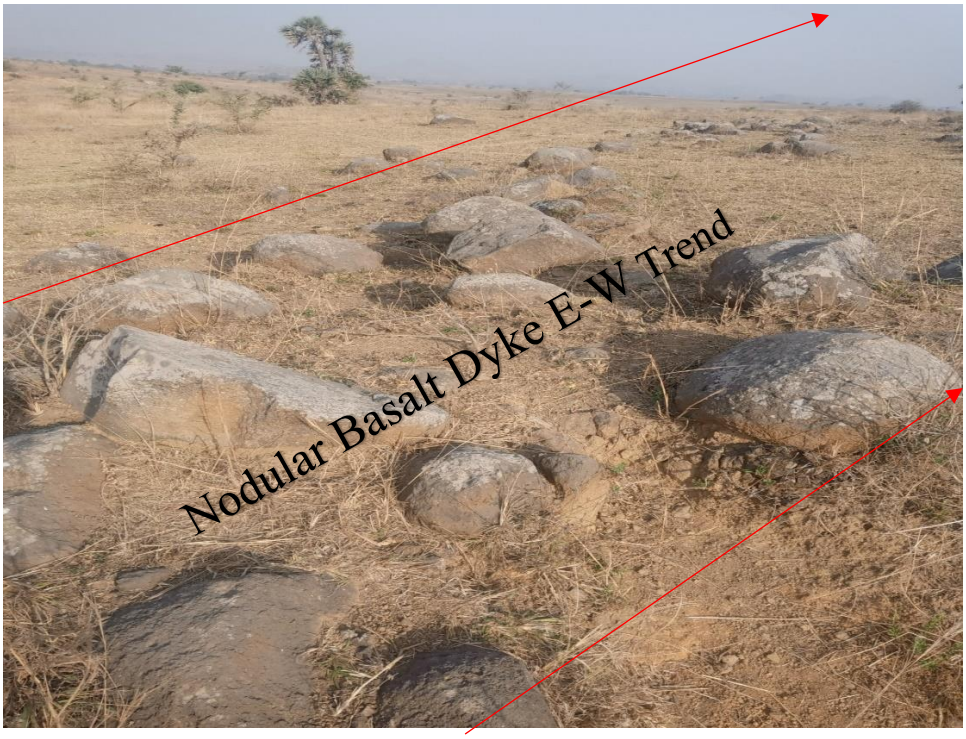


Plate 10: Nodular Basalts occurring as Dykes (E-W Trend) within Wereng Camp of Wereng Village.

Geochemical composition

Whole rock geochemical content has been determined on the Iron caps (GM1 and GM2), reddish-brown laterite (GM3and GM4), reddish-brown + intercalated Kaolin (GM5 and GM6), the yellow Laterite (GM7 and GM8), Yellow and White Kaolin (GM9 and GM10), pit samples of Tin Baring sediments (GM11-20), the Nodular Basalt (GMB1 and GMB2), Gneiss (GNS! And GNS2) and finally the Biotite Granite (PBG1 and PBG2). Results of the representative samples is thus presented in the Table 2.

Harker Daigram

The composition of the samples plotted on the Harker diagrams (Fig.7) reveals some attributes. There is relatively little correlation of the samples, owing to their distinctive composition. Alumina shows a corresponding increase in the Kaolin and pits samples, while Iron Caps are depleted in Silica saturation. There is depletion of sodium and Magnesium in weathered saprolite, which suggests that there was total exsolution of sodium during weathering, and that the Basalt was more or less, of Iron-rich, than it is Magnesium. There is a perfect negative correlation between ferromagnesian and Silica.

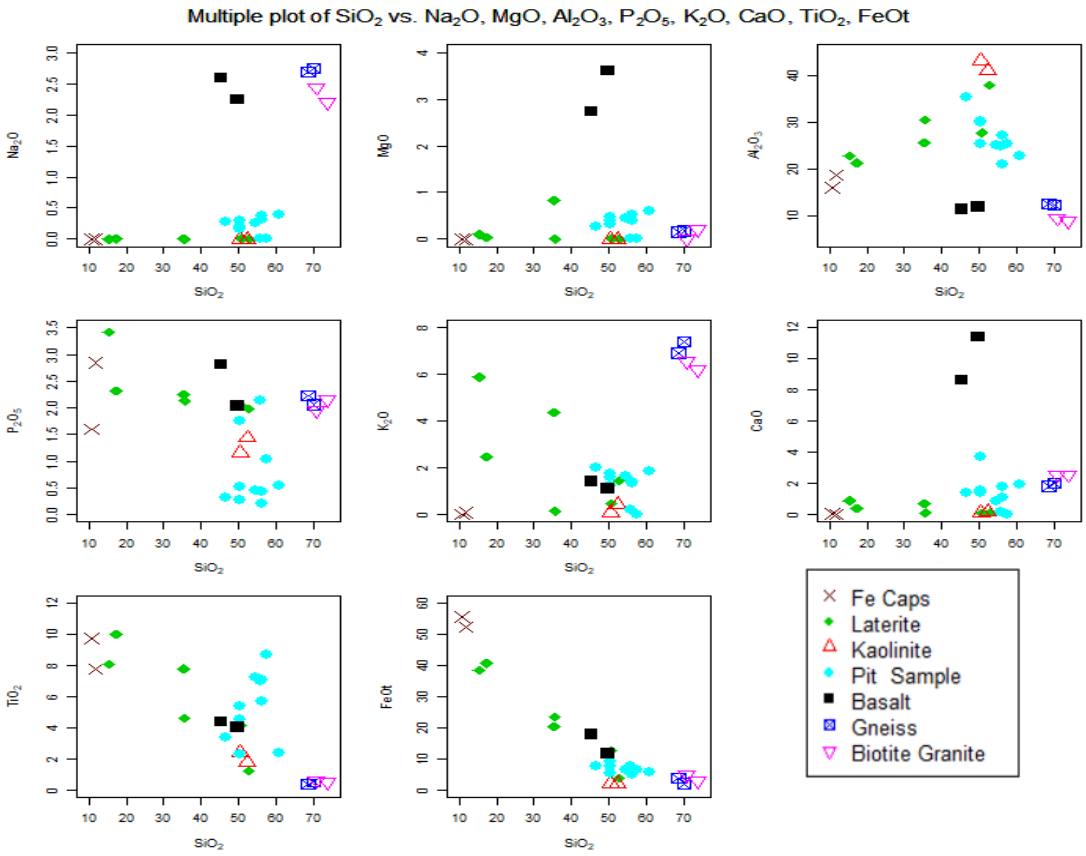


Fig 7: Harker Diagrams for Rocks showing Major Elements against Silica

Classification

The entire samples on the AFM diagram displays high total Fe_2O_3 and alkali, but shows low MgO values (Fig 8).

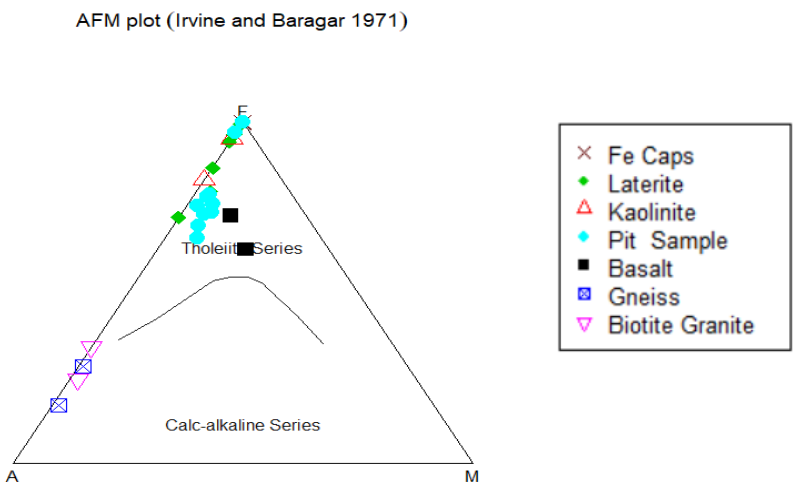


Fig 8: AFM Plot after (Irvine and Braga 1971) showing Basalt and corresponing saprolites falling on the Thoelitic series, while the Gneisss and Biotite Granite as Cal-Alkaine Series.

Feldspar Diagram

Feldspar plot for the rock types: Biotite Granite (PBG1BG2), the Gneiss (GNS1 and GNS2) and the Nodular Basalt (GMB1 ad GMB2)

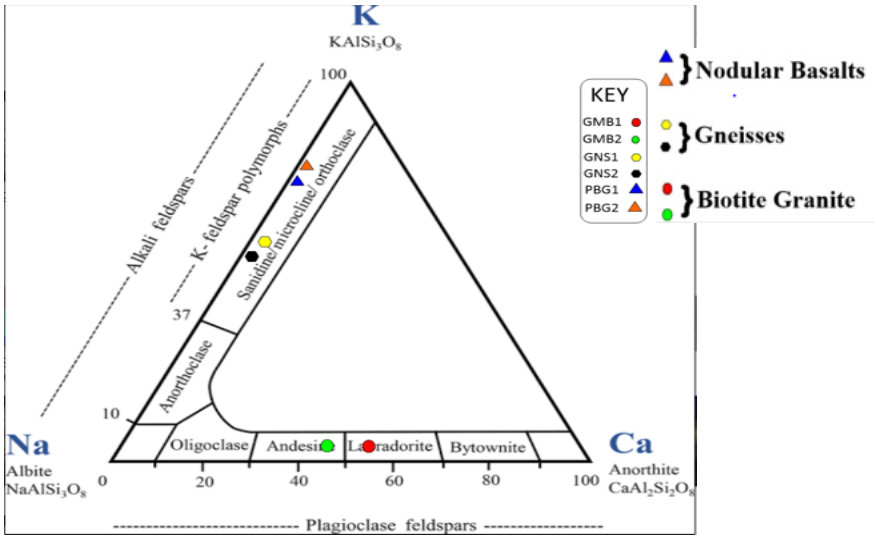


Fig 9; feldpsar plot for the Rock Types(Gneiss, Granite and Nodular Basalats), with the Biotite Granite within the Andesine and Labradorite (Plagioclase)enrichment, while the Gneiss and Nodular Basalt (sanidine/Microcline) and Nodular Basalts within Miccrocline/Orthoclase.

Tectonic Discrimination

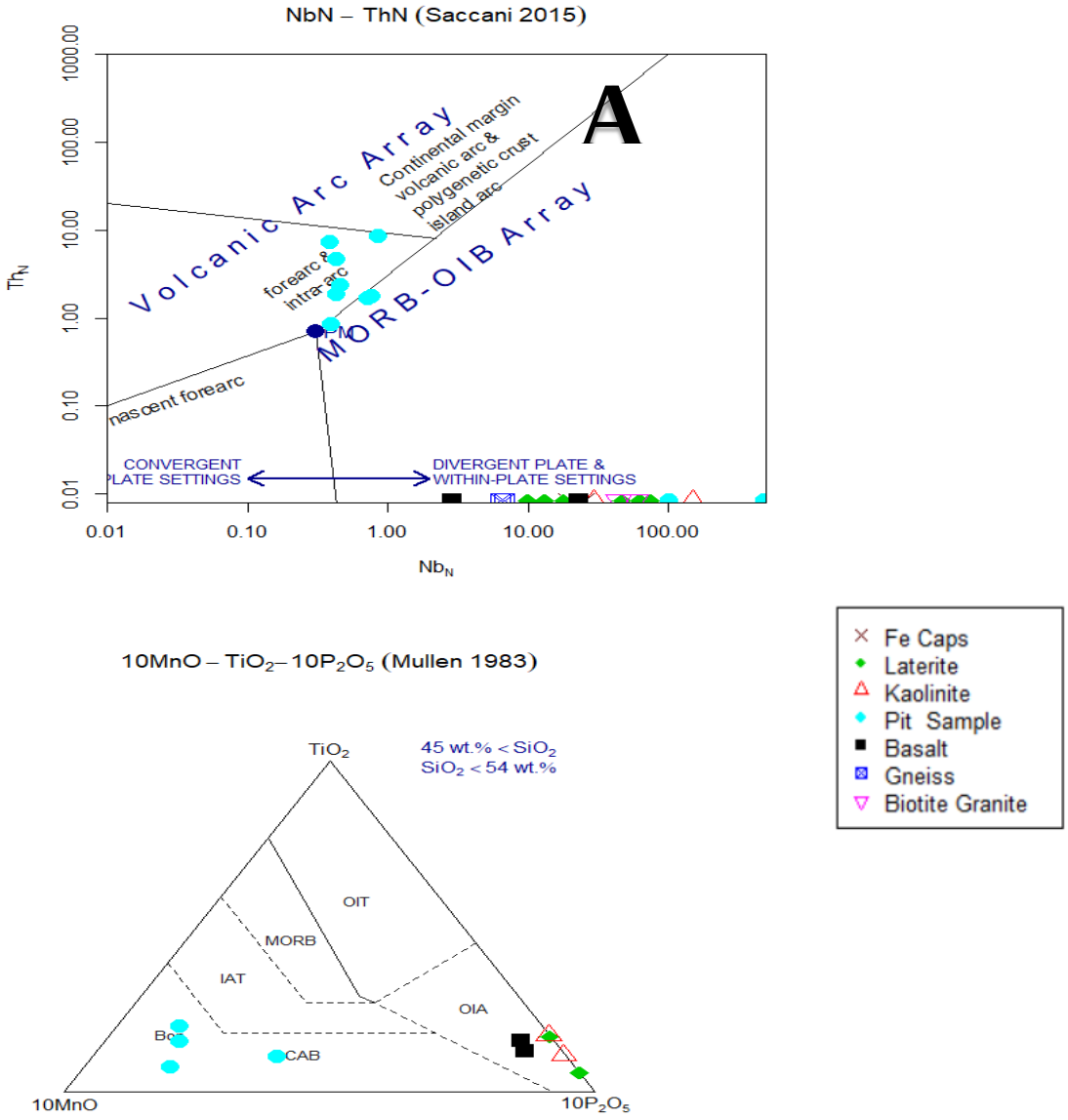


Fig 10 (A) a Recent model By Saccani (2015) NbN-ThN for volcanic rocks shows that the Basalts and corresponding Laterite are of divergent & Within Plate Settings, as well as forearc & intra-arc of Mid Oceanic Ridge Basalt(MORB). (B) a model by (Mullen 1983)MnO-TiO2-P2O5 shows Ocean Island Arc Alkali Basalts (OIA) and Calc Alkali Basalts (CAB)

Multielement Diagram

On the Chondrites (Thomson, 1982) Multi-element Variation diagram (Spider Plot), (Fig) majority of samples show pronounce positive enrichment of both High Strength Field and Trace Elements such as in the case of Ba-Nb-Zr. There is however a depletion of Rb-Ce and Hf.

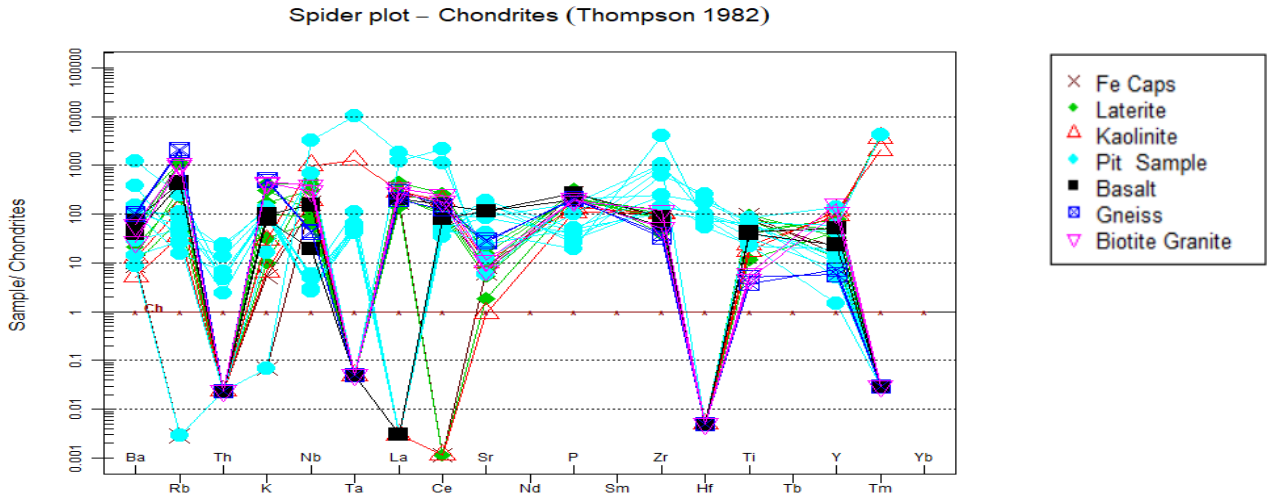


Fig 11: Chondite Normalized Spider Diagram of Trace and High Strength field Elements of the samples within the study area (Thomson 1982).

Prolificness of the Tin Layer

The Tin bearing sediments layer within Wereng axis consist of brownish loosed sand and gravels, having a thickness of 2.5-4m. Geochemical investigation of this sediments sampled from 10 pits shows a great deal of Tin concentration range of (40,000-62,000ppm) per every 1.5kg of sediments sampled. Other mineralization within the sediments includes, Zircon and Ilmenite and occurrence of Chromite. The total saprolitic overburden lying on the Tin bearing sediments is about 35-40m. The Tin deposit bearing sediment can only be access through pitting or tunneling.

PALEO RIVER/STREAM DIRECTION

Determination of the paleo-direction of river stream, valleys and erosional gaps hosting deep lead deposits, which especially have been submerged by pile of overburden sediments involves a multidimensional approach. Geologist and researchers employ various methods to reconstruct the ancient flow direction of river systems, shedding light on the formation and orientation of deep lead deposits which naturally takes alignment with the course of the river. (Blum, 2014) posited that understanding geologic maps of such areas is crucial in defining an establishing aptly the regional geology and distribution of sediments deposited. Erosional remnant, paleo-valley fills, and paleo-river terraces can be indicative to ancient river courses. Geologic maps aid in reconstructing the paleo topology of the river systems. Detailed topographic analysis, including the examination of modern drainage patterns, valleys, and ridges can provide clues about the historical flow directions of paleo river systems (Cunningham et al., 2016). Remote Sensing and GIS techniques such as analysis of satellite imagery and LiDAR data, aids in identifying geomorphic features associated with ancient river systems and their connectivity (Mitasova et al., 2009).

In an attempt to establish the orientation of ancient river/stream flow prior to the Tertiary-Quaternary geologic age, several parameters

were employed and integrated so as to locate, characterize, define and measure the deep-seated Sub-Basalt Tin deposits. This includes;

- The utilization and treatment of pit and tunnel data collected within Wereng areas to see if it gives any mineral concentration pattern within Wereng areas.
- Utilization and careful treatment of Remotely Sensed Electromagnetic and Aeromagnetic Data of the area under investigation. This is able to reveal the orientation pattern of heavy metal concentration, which would naturally take the course of the ancient river/stream, valleys and other erosional channels.
- Examination of modern drainage patterns, valleys, around Wereng areas, so as to obtain clues about the historical flow directions of paleo river systems.

Discussion

Of the total 26 samples obtained in the study area, 10 of which are pits and tunnel samples. After a careful geochemical treatment and investigation of the data, it was plotted, and an East-West (NE-SW) Tin Mineralization concentration Trend/orientation was established. It can hence be deduced that the ancient river streams/rivers had an E-W orientation prior to the deposition of the Tin within it.

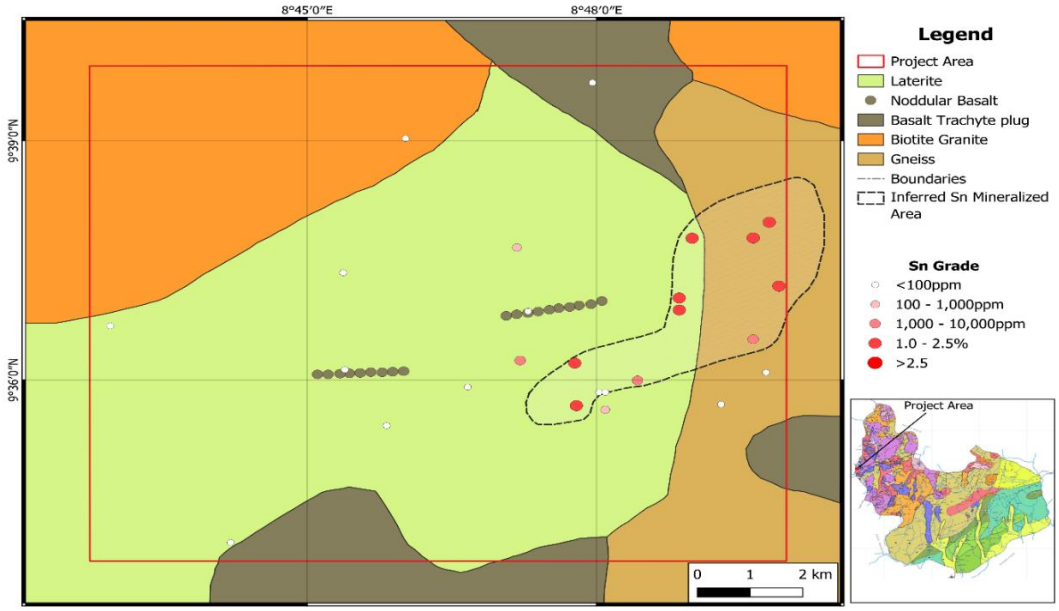


Fig. 12: Map of the Study Area Showing an NE-SW Tin Concentration Pattern in Wereng

Aeromagnetic Data of Wereng area acquired was interpreted, reveals the concentration of heavy metals (red bands) as shown in (Plate xx) exhibiting a NE-SW orientation. This further conforms and suggest that the heavy metals (Tin and others) from the Cassiterite greisens were weathered, eroded, transported, and deposited along the course of a NE-SW ancient river channel prior to the episodes of the Tertiary-Quaternary Basaltic Lava flow which was preponderance within Jos-Plateau, affecting the entire Wereng and environs

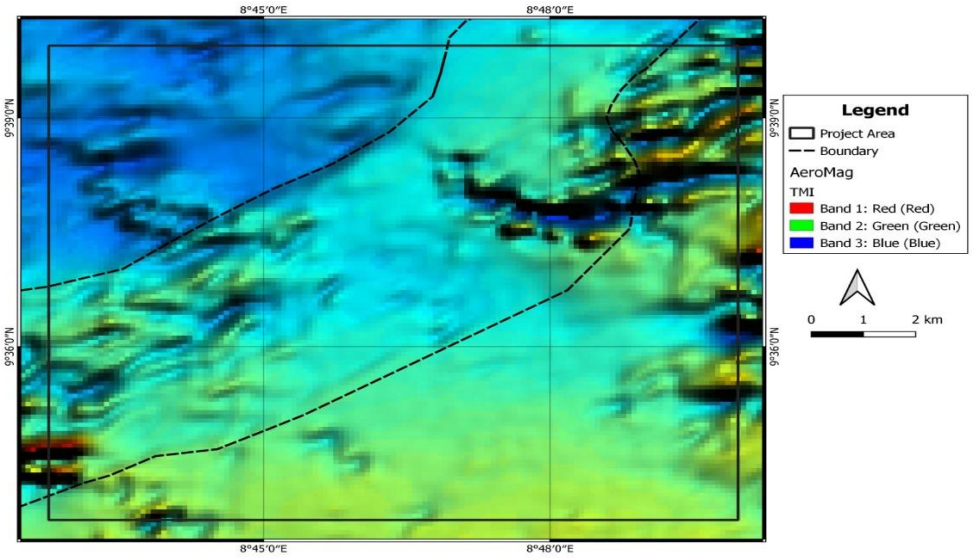


Fig.12: Aeromagnetic Map of Wereng area showing the concentration heavy metal (Red Band) exhibiting NE-SW orientation.

A careful examination of the modern drainage system and pattern within Wereng area intrinsically shows conforming attributes to the preceding interpretations. A NE-SW orientational flow of the streams/river suggests that eruption of the lava flow of the Tertiary-Quaternary age partially relegated the older or ancient streams/rivers, but still maintained the same course to the new or modern channels. Thus in developing an exploration model for the Sub-Basalt Tin deposits, a careful considerations be given to the factor of ancient river/stream direction as shown in the outlines.

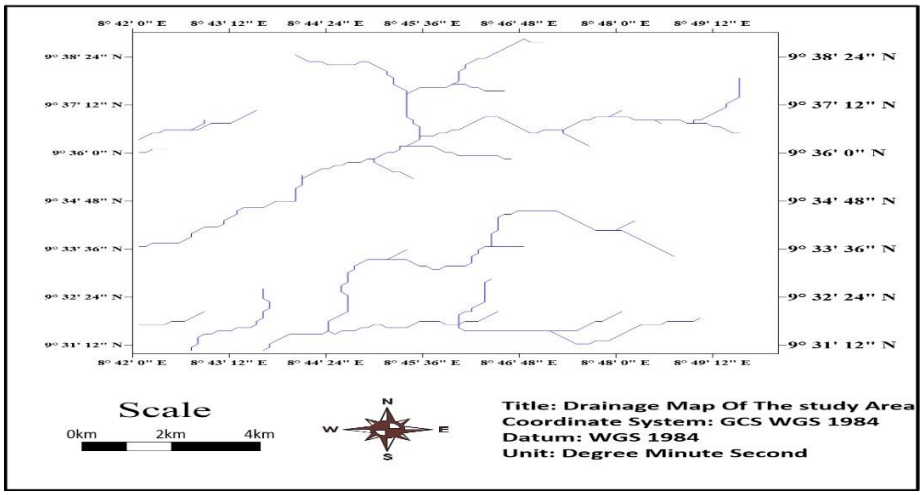


Plate (xx) Modern day drainage map of Wereng showing a NE-SW orientation which is a product of partial relegation of the Ancient River/Stream to the newer ones within the study area

IDEALISED MODEL OF WERENG AREA

The model below (Fig. xx) depicts and explains the processes and conditions of the area prior to when the greisenized Tin Granites was weathered, eroded, transported and subsequent deposition along the NE-SW trending ancient river/stream channels. It shows how the increasing upward oxidation and downward leaching of the Basaltic Lava flow during chemical weathering have resulted into the formation of Saprolitic layers/bands that are geochemically bounded- the Iron cappings/ferricretes, the reddish-brown laterite layer, reddish-brown laterite + intercalated Kaolin, the tallow laterite layer, and finally the peculiar Kaolin (of Basaltic origin) layer which directly overlies the Tin bearing sediment zone. This model also reveals the occurrence of some elements found within the saprolitic layers such as Chromium (Cr) and Silver (Ag) which are of crucial considerations. In developing an exploration model for the Sub-Basalt Tin Deposits, this model reveals varying layers (overburden) which must be overcome before any success will be made in exploitation. The model also depicts the very stable Nodular basalts seen atop of the saprolites within the study area.

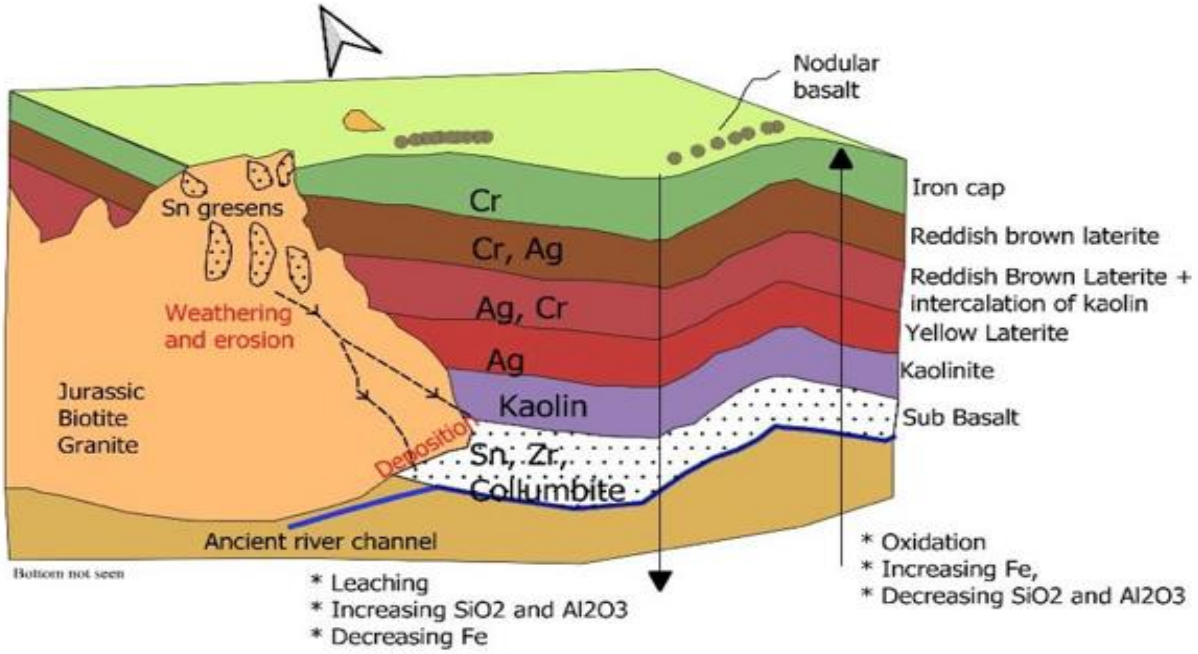


Fig. (xx) Idealized Model of the Sub-Basalt Tin of Wereng Area.

Conclusion

5.2 Conclusion

The conflation of field descriptive studies, geochemical data and interpretation, petrographic investigations as well as several other component indices of the study area have been considered, and hence the following conclusions have been drawn:

1. Tertiary-Quaternary Basaltic Lava flow was widespread, thereby burying Tin deposits concentrated along ancient stream/river, and valley beds within the study area, and have suffered great deal of chemical and physical alteration by the action of chemical weathering, resulting in the formation of saprolitic layers/bands of varying thicknesses whose boundaries are geochemically controlled and not lithological, and these include: The Iron caps, reddish-brown laterite layer, reddish-brown+intercalated Kaolin, the yellow laterite layer, and finally the Kaolin saprolite layer.

2. Geochemical and petrographic investigation reveals that the mineralized greisens of Biotite (Tin) Granite and the Basement rock (Gneiss) are petrogenetic to the origin of the Tin deposits concentrated within the ancient river/stream beds. This studies also shows the prolificness of the Sub-Basalt Tin within the area, as well as Zircon, Kaolin and Niobium.

3. The saprolitic laterite constitute an overburden thickness of 35-40m before reaching the underlying Tin enrichment zone which is 2-5m thick. The Iron Cap layer results from the greater levels of chemical oxidation of Iron materials, while the Kaolin represents most advanced form of downward chemical leaching of Feldspar materials of the Basalts.

4. The studies suggests that the direction of the ancient river/stream was NE-SW. This was deduced by integrating information from concentration trend of Tin obtained from Pit samples, aeromagnetic data which shows the heavy metals concentration trend of the study area, and a careful studies of modern drainage patterns. All of these shows a NE-SW orientation pattern. This is a very useful exploration tool of utmost importance.

Reccomendations

The following recommendations are hereby made:

- More drill holes should be made in other to obtain sufficient data for more detailed resource estimation which enhances the geologic confidence.
- More detailed and advanced studies be carried out on the Kaolin so as to establish a more precise grade for it, and preparing it for exploitation
- Detailed investigations be carried out on the high Chromium concentration seen occurring in all the saprolite layers, so as to unravel its health and environmental implications.
- Dating of the Nodular Basalts be carried out, so that their age is established.

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