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PII: S0375-6742(15)30065-0
DOI: doi: 10.1016/j.gexplo.2015.09.008
Reference: GEXPLO 5633

To appear in: *Journal of Geochemical Exploration*

Received date: 11 November 2014
Revised date: 2 August 2015
Accepted date: 13 September 2015

Please cite this article as: Arhin, Emmanuel, Jenkin, R.T., Cunningham, Dickson, Nude, Prosper, Regolith mapping of deeply weathered terrain in savannah regions of the birimian lawra greenstone belt, Ghana, *Journal of Geochemical Exploration* (2015), doi: 10.1016/j.gexplo.2015.09.008

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Regolith mapping of deeply weathered terrain in savannah regions of the Birimian Lawra Greenstone Belt, Ghana.

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ABSTRACT:

A regolith map for the Lawra Belt has been developed by categorizing the regolith-landform units by processing and interpreting remote sensing data. Regolith landform units were extracted from Landsat band ratios 3/1 and 5/4 to map ferruginous saprolite and lags; band ratio 5/7 was used to identify residual regolith and band ratio 4/2 was employed to separate ferruginous units from non-ferruginous regolith. Additional regolith landform units' discrimination was provided by compiling and interpolating radiometric data particularly for Landsat TM poorly defined areas. SRTM images were used to mark out the extent of the alluvial plains. High topographical terrains were marked from DEM image to represent the residual areas. Regolith landform unit (RLU) map that showed residual (relict and erosional), ferruginous, and depositional domains of the Lawra Belt was developed by superimposing the extractions made from the remote sensed data. Interpretive map generated from the remote sensed image analysis was validated by first creating a non-genetic regolith map through ground truth survey. The non-genetic map based on

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spatial distributions of the different regolith mapping units were classified on genetic classes or regimes based on regolith-landform similarities to develop a genetic map. The interpretive and the genetic map were superimposed to develop the regolith map for the Lawra Belt. The inliers and outliers presenting compositional overlaps within broad regolith classes were rectified from the field mapping information. The combined approach of image analysis and the ground truth mapping grouped the regolith of Lawra Belt into ferruginous (F), relict (R), erosional (E) and depositional (D) regimes.

Keywords: Landscape, Regolith, Map, Lawra Belt, Savannah, Ghana.

1.0. Introduction

A regolith map is a spatial representation of regolith units on the landscape (Anand and Smith, 1993). This map can show different regolith domains based on regolith evolution, geomorphic expression and weathering histories. Representing the landscape to a map form may assist in clarifying the relationships between parent and surface materials (Anand et al., 1993; Anand and Paine, 2002). Maps that show the different regolith-landform units provide the user a picture of the spatial association of regolith mapping units from which relevant information can be extracted for regional geochemical exploration (Bolster, 1999, Arhin and Nude, 2009). Well-developed regolith maps can guide regional soil geochemical anomaly interpretation and can be used to identify false anomalies (Bolster, 1999; Arhin and Nude, 2009).

Rapid changes that occur in the landscape over time during weathering, erosion, transportation, deposition and lateritisation as climate changes have implications for geochemical gold exploration. The changes enhance local re-distribution of surface

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regolith materials that may create surface geochemical signatures unrelated to the effects of underlying mineralisation. Whilst enhancements of geochemical signatures may be locally expressed in the regolith in some areas, elsewhere the elements distribution become erratic with a mixture of high and low geochemical expressions. If the source material is related to mineralisation, then residual anomaly will form over the source mineralisation whilst superimposed displaced anomaly forms elsewhere away from the mineralised source. During lateritization processes both residual and exotic sediments are cemented by Fe-oxides and clay minerals. Metals that have affinity for Fe-oxides will be trapped in the Fe-oxide nodules in lateritic residuum, lateritic duricrust and ferruginous duricrust or ferricrete. The trapped metals adsorb in the Fe-oxide nodules by sorption reaction will reduce the geochemical expressions. This is because the nodules may constitute a portion of the coarse fraction either in the lateritic duricrust or ferruginous duricrust that are sieved out, discarding the trapped metals in the Fe-oxide nodules. Therefore, understanding the regolith architecture and creation of regolith maps that show the distributions of the regolith materials will contribute considerably to the way surficial geochemical data are interpreted. The processes that contribute to the complex dispersal of the surface regolith are also involved in the geochemical dispersion processes in the surface regolith. Therefore, if the processes involved in the disorderly distribution of regolith materials are also involved in the geochemical dispersion, then putting geochemistry in a regolith context can alleviate some of the challenges of geochemical data interpretation within the study area.

In complex regolith terrains, residual anomalies can be distinguished from transported anomalies by matching the regolith map with surface geochemical data (Cohen et al.,

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2010). Similarly, weathering, erosion and depositional processes that transport and redistribute regolith materials and influence element dispersal patterns can be determined (Bradshaw, 1975) during mapping. Regolith maps that show the relationship between landform distributions and their associated regolith types are available in most parts of Australia (e.g. Anand and Smith, 1993). Conversely, regolith maps that illustrate landform/regolith inter-relationships are only available locally in some parts of West Africa (Bolster, 1999, Arhin and Nude, 2009). Careful study of few published regolith maps available in the West African Sub region shows that particular landscape models that apply in one place do not necessarily apply elsewhere. This therefore necessitated the development of a map that accounts for the rapid changes of the landscape due to changes in climate, geomorphic and weathering histories to standardise regolith mapping steps in the savannah regions of West Africa using the study area as an example. The mapping method used involved remote sensed data interpretation that classified the landscape into different regolith-landform units after which field checks on the mapping units were validated to affirm the interpretation of the landscape from the remote sensed data. The methods used in developing this regolith map aimed at:

1. Standardising mapping techniques for generating regolith map for the savannah regions of the Birimian Lawra Belt of Ghana accounting for geomorphic and weathering histories and
2. Highlighting the role of regolith mapping particular for regional geochemical exploration in the savannah regions.

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2.0. Location and geology of the study area

The study area is located in the Lawra Birimian Belt in northern Ghana (Kesse, 1985). The detailed regional geology is shown in Fig. 1. The area is 700 km northwest of Accra, the national capital. Underlying the area are metamorphosed lavas and pyroclastic rocks plus dolerites that are locally intruded by gabbro (Leube et al., 1990; Liegeois et al., 1991; Hirdes et al., 1992; Doumbia et al., 1998; Oberthur et al., 1998; Egal et al., 2002; Gasquet et al., 2003; Naba et al., 2004; Feybesse et al., 2006). At the north-eastern and central parts of Lawra Belt also are dark grey to greenish grey, weakly foliated mafic extrusive volcanic rocks, partially assimilated with melanocratic relicts (xenoliths) in close association with granitoids (Nude and Arhin, 2009). The metasedimentary units consist of phyllite, sericite-schist and meta-greywacke that are locally intruded by felsic and mafic dykes.

However the Birimian rocks of southern Ghana have migmatite and granitic intrusions that have generally been classified into two broad categories (Leube et al., 1992). These are hornblende-rich varieties that are closely associated with the metavolcanic rocks and known as the ‘Dixcove’ or ‘belt’ type; and mica–rich varieties which tend to border the volcanic belt. Recent work by Baratoux et al. (2011) confirmed the occurrences of these intrusive bodies in both the sedimentary and the volcanic rock suites in the Lawra Belt. The belt granitoids are small discordant to semi-discordant, late or post-tectonic soda-rich hornblende-biotite granites or granodiorites that grade into quartz diorite and hornblende diorite (Hirde et al., 1996). The belt granitoids are generally massive, but in shear zones they are strongly foliated. The basin granitoids are large concordant and syntectonic batholithic granitoids commonly banded and exhibit black and white foliations. They are potash-

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rich and contain both biotite and muscovite, with the biotite dominating (Leube et al., 1990). These intrusive bodies have isoclinal folds with dips usually greater than 50^{o}. The general strike of rocks is N–NNE to S-SSW.

3.0. Regolith mapping methods

The regolith map development involves data collection, interpolation and compilation. Data collection consists of remote sensing image analysis and fieldwork. In this study satellite images from SRTM (Fig. 2 A), DEM (Fig. 2 B), Landsat TM (Fig.3) and Ternary radiometric image (Fig. 4) were collected. These data were processed and interpreted using ENVI 4.7 and geographic information system (GIS) to classify the landscape into the various regolith-landform units (RLU).

3.1. Image analysis

The landform was used as surrogate for regolith in this mapping because landform boundaries tend to be sharper than many landform characteristics. Landscape features representing high and low reliefs were compiled and interpolated from the DEM image. The high relief landscapes were assigned polygon-class with black colour to represent the residual environments. The SRTM image was also interpreted to compile and interpolate limits of catchment areas of drainage systems. Different polygon-classes colours, example deep blue and light blue were also assigned for catchment areas close to rivers and stream channels to depict distal sediments and those away from rivers and streams to mark the proximal sediments. The residual and transported environments were compiled from the superimposition of DEM and SRTM images (Fig. 5). The merged regolith-landform unit boundaries from DEM/SRTM superimposition showed extensive unclassified areas. The inability of

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the compilation of regolith-landform boundaries derived from SRTM superimposed over hill-shaded DEM might be due to many parts of the study area having extremely low lying terrains. Marking out alluvial plains in areas of no drainage systems and defining residual areas from low reliefs could lead to misclassification of the regolith-landform boundaries. In completing the regolith-landform units classification for the unclassified areas Landsat TM and radiometric images were used.

Landsat TM with ground resolution of 30 m (Fig. 3) was used to add more regolith-landform information to the unclassified portions of the SRTM interpretive map (Fig. 5). Using landform as a surrogate to regolith, the topographic terrains were assumed to represent residual environments. The high level terrains on the DEM image (Fig. 2 B) were designated to have residual regolith. The compilation and interpolations made on the DEM image were draped on the SRTM interpretive map. The compilation and interpolation made on the superimposed map of SRTM/DEM allowed in the broad classification of depositional and residual environments (Fig. 6).

Further image analysis was carried on the Landsat TM using selective principal component analysis (PCA). This method uses two band ratios to distinguish subtle changes in the image to represent some regolith units. In this study Chavez and Kwarteng (1989) method of using two bands from the same image was used because of their successfully application to discriminate different ferruginous units. The spectral enhancements that discriminated the different and subtle variations in regolith types employed band ratios of 3/1 to map ferruginous saprolite and lags, band ratio 5/4 to discriminate residual and transported clays, band ratio 5/7 to distinguish the varying ferruginous units and band ratio 4/2 to discriminate ferruginous units from non-ferruginous regolith. The subtle changes in spectral responses were assigned different polygon-classes with different colours to represent different regolith boundaries. The regolith-landform units' boundaries compiled and interpolated from the processed Landsat TM image was superimposed on the STRM/DEM interpretive map to assign regolith-landform units for the unclassified areas (Fig. 7). Additional compilations and interpolation to improve the poorly defined portions of the unclassified landscapes from the processed Landsat TM image were supplemented from 50 m ground resolution radiometric data (Fig. 4).

The radiometric data was measured from the abundances of K, Th and U in rocks, weathered materials and soils and their emissions detected by gamma-rays from natural isotopic radioactive decay. Archival report indicates 90% of gamma-rays emanate from the top 30-45 cm of dry rock or soils and intensity of emitted gamma-rays relates to mineralogy and geochemistry of the surficial materials (Dickson and Scott (1997). Ternary radiometric image (Fig. 4) interpretations in this research followed Wilford et al. (1997). High K concentration areas shown red or shades of red in the ternary image refer to shallow outcrop and areas overlain by colluvium dispersed down slope from exposed basement rock. The U-rich represented in blue or shades of blue colours represent depositional areas. The green areas representing Th-rich terrains characterises the semi residual landscapes. Using Wilford et al. (1997) criteria, polygon-classes with different colour-codes were drawn on the image to discriminate the radioactive elements K, Th and U enrichment and depletion zones in the area. Compilation and interpolations derived from the ternary image was draped on the SRTM/DEM and Landsat compiled interpretive map to produce the regolith-landform unit map (Fig. 8). This map is the regolith-landform unit map developed

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from the image analysis. Final regolith map that incorporate geomorphic processes and weathering histories require ground truth mapping to test the correctness of the interpretive image analysis map. The final regolith map is an integrative map that includes the validated interpretive regolith-landform unit map and the ground truth non-genetic field regolith-landform data.

3.2. Fieldwork

This constituted a follow-up field survey to validate the compilation and interpolations made during the image analysis. Data from mapping units on land surface and at depth up to 3 m or to the sap rock were recorded. This involved regolith-landform information collections from ferruginous materials whether in situ, transported or unknown, and also from weathered materials such as ancient weathered surfaces left in their original place or without significant lateral movement. Regolith-landform data were recorded also for environments showing partial and fully truncations exposing mottled zone, plasmic zone, saprolite, saprock and bedrock. In addition data on sediments dominated terrains comprising colluvium, alluvium and aeolian deposits over varying lithological units were gathered.

A non-genetic map (Fig. 9) derived from ground truth data based on spatial distributions of the different regolith mapping units recorded were used to developed a genetic map (Fig. 10). The genetic map was designed on the broad classifications of the non-genetic map which include three regolith classes based on the original RED scheme and an additional regolith layer to contain the Fe-oxide-rich regolith units. Modes of formations of the ferruginous units are as a result of secondary re-cementation of the unconsolidated regolith units. They can form in relict and

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depositional regolith. Including laterites formed from residual weathered materials in relict and laterites formed from exotic and redistributed sediments can results in surface geochemical data challenges. The inclusion of ferruginous regolith as part of the original RED scheme is because of the lack of exploration successes in this area. The grouping of non-genetic mapping units to genetic classes or regimes based on regolith-landform similarities include:

1. Relict regime (R) that represents a grouping of regolith mapping units that are characterised by the occurrence of lateritic residuum at or close to surface. In situ soils and soils with insignificant lateral movements were included in this regime. This regolith domain represents an ancient weathered surface but the grouping was based on factual observation during the field ground truth mapping.
2. Erosional regime (E) also represents a grouping of regolith-landform mapping units in partly eroded and fully eroded regolith-dominated terrain characterised by outcrop and subcrop of mottled zone, plasmic zone, saprolite and bedrock etc.
3. Depositional regime (D) is also a grouping of regolith mapping units in regolith-dominated terrain characterised by widespread sediments that may overlie lateritic residuum, saprolite or bedrock.
4. Ferruginous regime (F) pertains to regolith having obvious Fe-oxides. This includes lateritic duricrust, lateritic gravel, ferruginous duricrust or ferricrete and all ferruginous materials whose origins cannot be identified easily in the field.

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Stage 1

The first stage of the fieldwork was a reconnaissance survey at the Lawra Belt marked out for the study (Fig.1). This phase of the survey was carried out at representative part of the area in terms of regolith types and accessibility. Base-map indicating the location of different regolith-landform units in relationship to transport routes were produced from the landscape classification map as a guide before going into the field, Defined regolith-landform areas classified from the image analysis were selected on or near roads and tracks for validation. General observations of the regolith units and landforms were made whilst traversing to some defined regolith regimes for field confirmation. Traverses were also made to some poorly defined regolith-landform areas that showed overlapping information from the image analysis. These areas were driven through whilst information on the regolith mapping units, regolith toposequence and distributions of the unconsolidated units and Fe-oxide-rich soils cemented to form laterites were recorded. During the reconnaissance survey regolith-landform unit information were captured and use through the study by assigning upper-case letters for landform type and lower-case letters for regolith type whilst surface modifier were denoted numbers. Details of regolith-landform attributes are presented in Table 1.

Stage 2

This stage involved closed-spaced collection of regolith mapping units at a scale of 1:50 at the defined regolith classes (FRED). GPS and cut-line traverses to areas recognised from the interpretive landscape classification map to represent ferruginous, relict, erosional and depositional regolith-landform units were mapped. Records of regolith surface materials along the traverses using similar regolith-landform

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descriptors used during the reconnaissance survey were applied. Depth information was also collected at shallow and deep exposures particularly from road cuttings, stream banks, gullies, construction sites and gravel pits. Similarities of superficial regolith materials across different interpreted regolith regimes were discriminated from shallow and deep excavations. Extrapolations of regolith units were done based on correctness of interpretive map in relationship to the ground truth data. Where shallow and deep excavations were uncommon 1.0 m x 1.0 m pits were dug up to 3.0 m depths. This was carried out in each defined FRED domains. In the pits, natures of successive regolith horizons were examined and the characteristics of the respective regolith profiles compared layer by layer to a complete lateritic profile. Complete laterite profile from bottom up contains sap rock, saprolite, a mottled zone, +/- laterite zone and upper soil or organic influenced soils. Regolith data collected in the pits were nature of the regolith horizon boundaries; presence of unconformities between adjacent horizon boundaries and regolith material textures including cementing matrix and the framework constituents.

Stage 3

Poorly defined regolith classes that occurred as inliers in the broad classifications made during the image analysis maps were subjected to a scale of 1:20 mapping. Pitting to provide down depth information on the regolith profile were also carried out. Fe-oxide rich areas may be underlain by laterites form from residual weathered materials or formed from cementation o exotic redistributed sediments. These areas were subjected to pitting for down depth examination of the pit profiles. Observations made in the pit profiles included the equal and uniform grain size matrix materials and some remnant expressions of the underlying rocks and the polymictic matrix character

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of some ferruginous units. Pits in ferruginous terrains characterised by detrital or clasts-supported laterite, shape and smoothness of pebbly fragments forming the framework of the Fe-oxide rich laterite were used discriminate the laterite types. In pits or deep exposures at duricrust hills or at plateau faces, ferruginous residual accumulation of weathered materials on hilltops form concave downwards interfaces between the laterite and the hill, whereas those formed in valleys, streams or former low-lying terrains but because of landscape evolutional processes (e.g. relief inversion) show concave upwards interfaces between the hilltop and the laterite.

Similar scales of mapping supported by two or three pits were carried out at relict and erosional regolith terrains. The image analysis interpretation identified portions of the landscape to have residual covers but unable to discriminate them into relict and erosional regolith. Cumulative profiles representing relict environments and composite profiles characterising erosion regime that show overprints and mixing between weathering profiles in basement and those in sediments were easily detectable. Other areas such as depositional and relict landscapes with thin cover of recent sheet-wash deposits may have visual similarities to the surface regolith and can cause misclassification unless 3D regolith information is available. Pits were dug at some of these areas where possible.

Stage 4

This phase was the last stage in the regolith-landform map development for the Lawra Belt. The genetic map (Fig. 9) created from the non-genetic map (Fig. 8) was superimposed on the interpretive landscape map (Fig. 7) to validate the correctness of the remote sensing regolith interpretations. Polygon classes assigned with different

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colours to define major regolith-landform boundaries on the interpretive map were refined where necessary with the regolith ground truth data. This was done in GIS environment where the genetic map (Fig. 9) was draped on the interpretive landscape regolith map (Fig. 7) to form the integrative regolith map (Fig. 10) to represent the spatial distributions of FRED regolith domains that incorporated geomorphic and weathering histories of the Lawra Belt. The genetic map (Fig. 8) draped over the interpretative map (Fig. 7) was used to correct areas with conflicting regolith class. The corrected-cleaned composite regolith map formed the final regolith map (Fig. 11) of the Lawra Belt.

4.0. The role of regolith mapping in mineral exploration surveys

Understanding variations in the regolith environment is of great importance for interpreting the geochemistry of regolith units and buried bedrock. The predominant regolith class can be observed at a glance from the regolith map which can guide in planning the surface geochemical survey. It can inform the planner of the surface geochemical survey to use appropriate sample spacing. Again it will prompt the exploration survey planners about the relative distributions of the different regolith regimes to give clues to what depth to sample either at same depth or at different depths.

This map (Fig. 12) geochemically discriminates residual regolith areas from environments covered by exotic transported materials. Any of these regolith unit types can host mineral anomalies. But the residual anomaly will most likely relate to the underlying mineralization whilst the mineral enrichment in the transported materials may just be a superimposition of distance anomalies expression in the exotic sediments. The abnormal concentrations of metals in this regolith types may not relate

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always to the bedrock mineralization and may be separated from other regimes with this kind of map whilst interpreting geochemical data. With this the challenges in surface geochemical interpretation can be reduced. Besides metal levels in the different regolith domains will be understood because this map incorporates geomorphic and weathering histories in the map development. Example at residual regolith areas metal signatures will be consistently higher but lower in concentrations to the deposit itself near the source. However the dispersion halos in the redistributed sediments cover may be subtle, weak and erratic with occasional high metal level concentrations.

Using the developed regolith map for Lawra Belt as an example only small areas were mapped and interpreted to represent erosional surface. As noted by Anand and Smith (1993) the lateritic residuum did not form a widespread continuous unit on a peneplained surface but a discontinuous cover so if high geochemical assays are recorded for samples collected from these areas, they will appear as isolated high assays that may not relate to any big underlying mineralization. Possibilities of discontinuing geochemical exploration surveys in such an area may be high. Similarly if geochemical interpretations are not made with respect to the regolith environment, then conventionally high assay values may influence the selection of threshold values that may undermine follow up surveys in potential anomalous areas. Examples can occur in ferruginous and depositional regimes where surface geochemical expressions are influenced by the evolving regolith and landscapes. Ferruginous regime may have subtle and subdued anomalies because of metal coatings during lateritization processes and depositional areas have redistributed sediments showing erratic metal distributions due to uncontrolled deposition of regolith materials and elements by

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surface water, wind and in parts by gravity. It is apparent that the compositional variability of the surface regolith disapproves the use of a single threshold value for the various regolith regimes as their mode and environments of formation varies.

This decade has seen continued decline of world-class mineral deposit discoveries and has resulted in an increased attention on geochemical exploration in regolith-dominated terrains. Thus confirming Butt and Zeegers (1992) assertion that easy to find mineral anomalies have all been found in less complex regolith terrains. These and reports by Bolster (1999, 2007) and Arhin and Nude (2009) suggest producing a well-developed regolith map can help to define displaced anomalies unrelated to bedrock mineralization and thus contribute to reduce false-anomaly follow-on investigations. These sorts of information construed from regolith maps can guide in devising geochemical exploration survey that can detect hidden and non-hidden mineral deposits. For instance dispersion of metals in the secondary environment is controlled in part by the regolith type coupled with the chemical mobility and the mechanical element transport mechanisms. Dispersion halo size, intensity and location may have a link with the regolith type. Reported subtle, low and high Au concentrations in the study area by Griffis et al. (2002) can be an attribute of the extensive coverage of redistributed sediments and Fe-oxide rich covers shown in Fig. 12. As indicated by Anand et al. (2001), transported regolith can create a mix of low, high, subtle metal expressions mechanically at the surface environment. Typical of this kind of regolith is the extensive depositional regolith mapped (estimated to be about 72% extrapolating from the GIS software) in the Lawra Belt study area (Arhin 2013).

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5.0. Conclusions

The regolith of the Lawra belt has formed continuously over the years and continues to evolve under the present climate. This is evidenced in the cumulative, composite and compound surfaces formed as a result of the past and present geomorphic processes and weathering histories. The overprint of the continuous evolution of the regolith-landforms is expressed in the landscape and has been presented as the regolith map of the study area. The mapping of the regolith with the FRED scheme identified 72% of the landscape to have redistributed sediments that comprises recent and proximal sediments (Arhin, 2013). The remaining 28% consist of relict, erosional and ferruginous regolith. It was recognised during the study that landscape classification from image analysis alone was insufficient for identifying some regolith features. Therefore, development of regolith maps aimed at detecting mineralisation under cover requires field inspection to validate and improve the landscape classification results. The study recognised the mapping methods used in developing the regolith map as appropriate in creating regolith maps in the savannah regions of Ghana and similar areas in West Africa..

In summary the following steps can be carried out to create regolith maps in complex regolith terrain for geochemical mineral exploration surveys:

i. Landscape classification of the regolith should be done at regional scale to identify different landscape variables to be investigated during follow-on field mapping.
ii. Ground truth mapping should be carried out after the landscape classification to authenticate areas that were difficult to define from the image analysis.

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iii. Depth characterisation of the regolith profile should be carried out by digging pits, and observing and logging other deep exposures for 3D information.

iv. Improved discrimination of regolith boundaries interpreted from image analysis and the observed ground truth information should be carried out in the field. It is recommended that any decision about regolith contacts and inclusion or exclusion of areas in various units should be done in the field, preferably soon after the ground truth mapping observed some contradiction in feature from the image analysis and interpretations.

Finally, the applications of the regolith mapping techniques used in this paper will help resolve the difficulties of selecting sample media and spacing. Additionally, the integration of regolith maps and surface geochemical maps or images can highlight unreliable anomalies that hitherto might have been followed up because a displaced anomaly could be considered a potential exploration target. Therefore, to better meet the exploration objectives of discovering new world-class ore bodies or potential anomalies that are hidden under cover in the savannah regions or semi-arid areas, application of regolith mapping during surficial geochemical data interpretation is critically important.

Acknowledgements

WAXI/AMIRA funded the study. The authors wish to thank them for the sponsorship. Comments and suggestions by anonymous journal reviewers and helpful comments by the journal editor are very much appreciated. Also, to all that contributed directly or indirectly in this study, we thank you so much.

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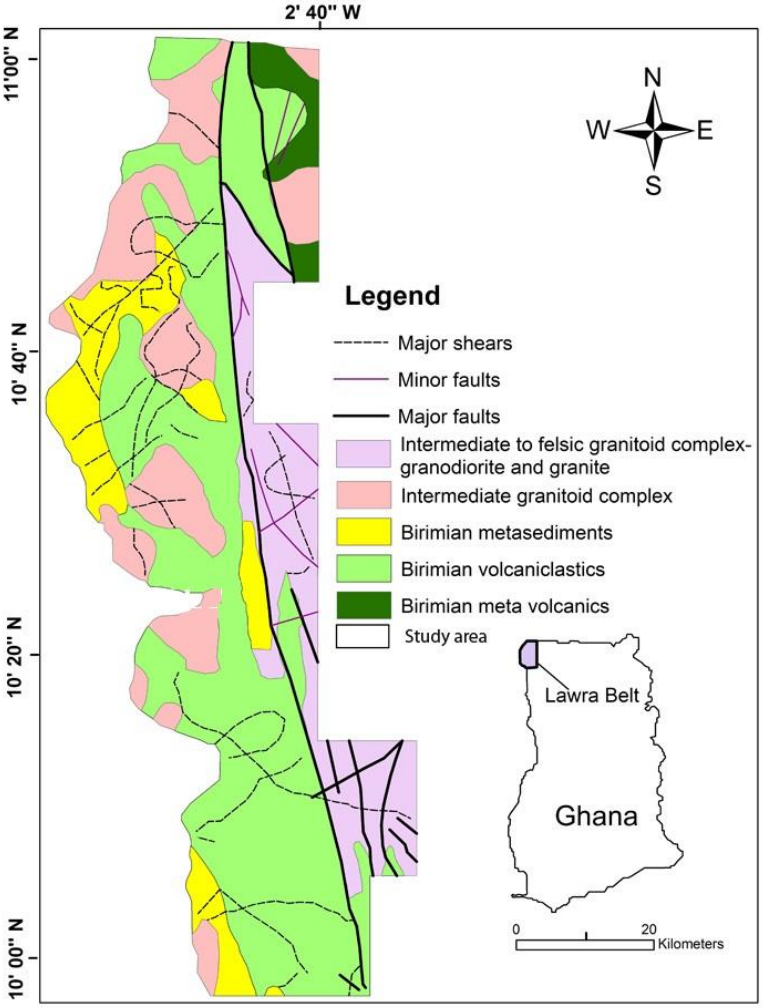

Fig. 1

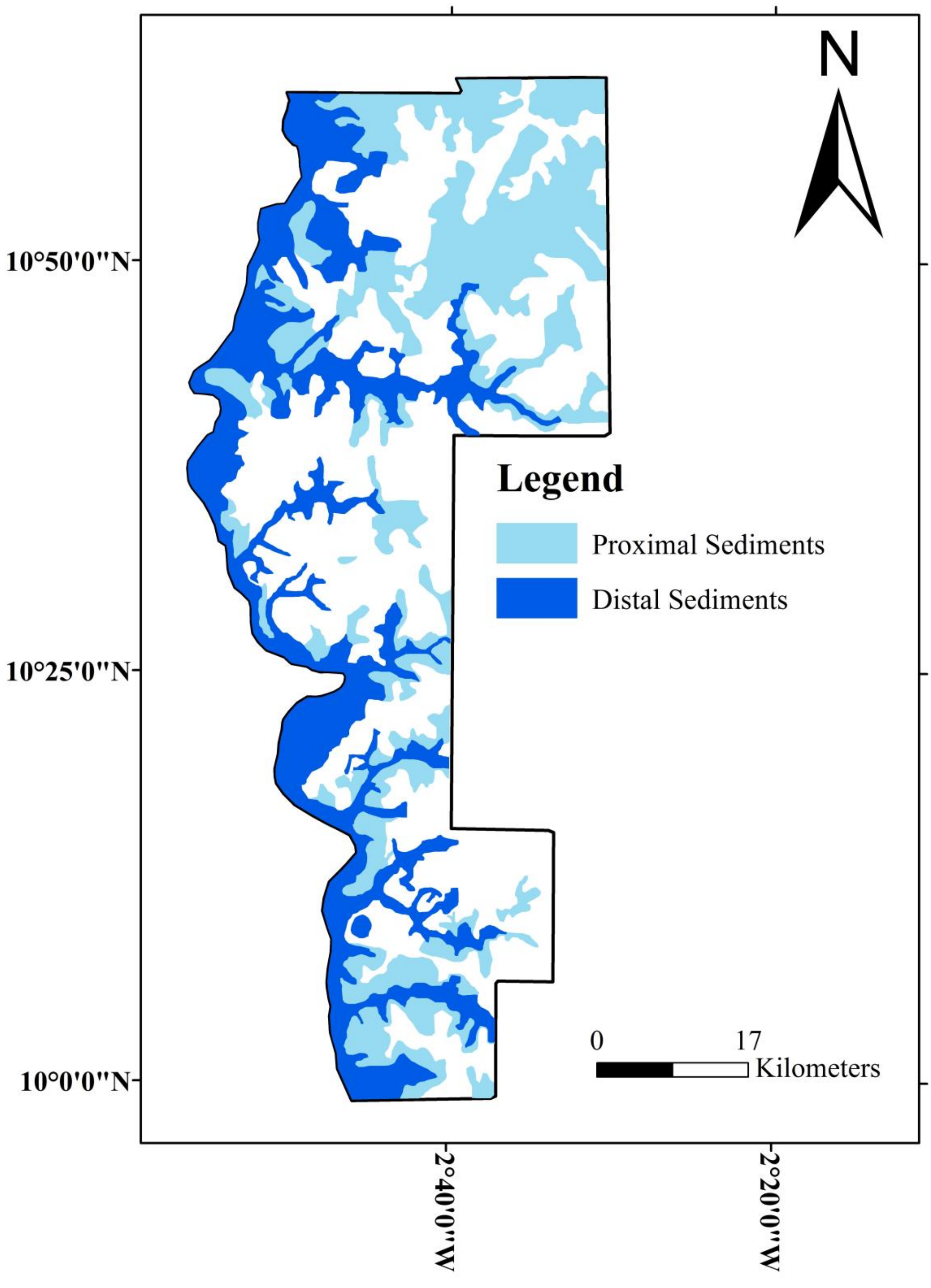
N
Legend
Proximal Sediments
Distal Sediments
10°50'0"N
10°25'0"N
10°0'0"N
0
17
Kilometers
2°40'0"W
2°20'0"W

Fig. 2

Fig. 3

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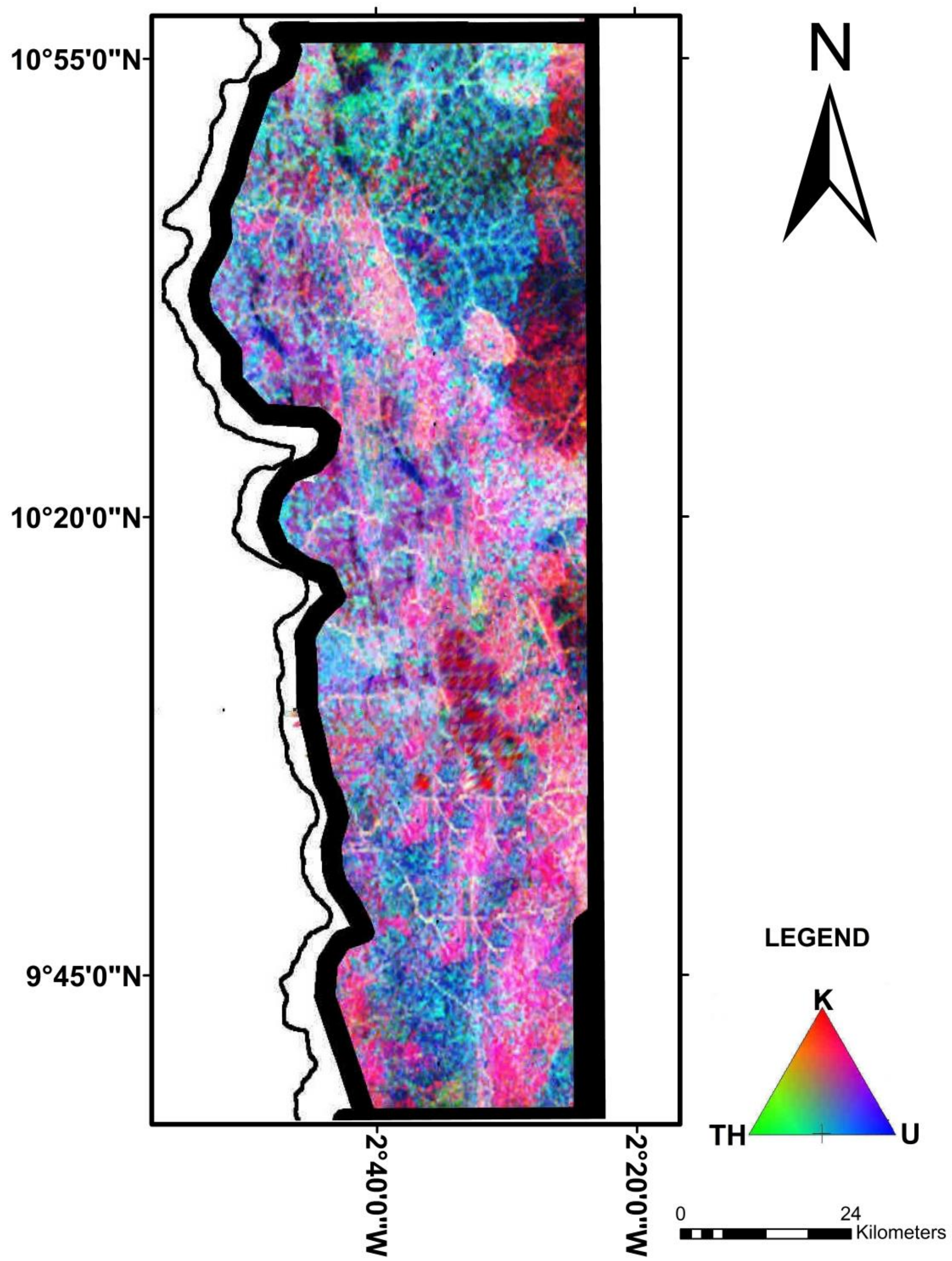

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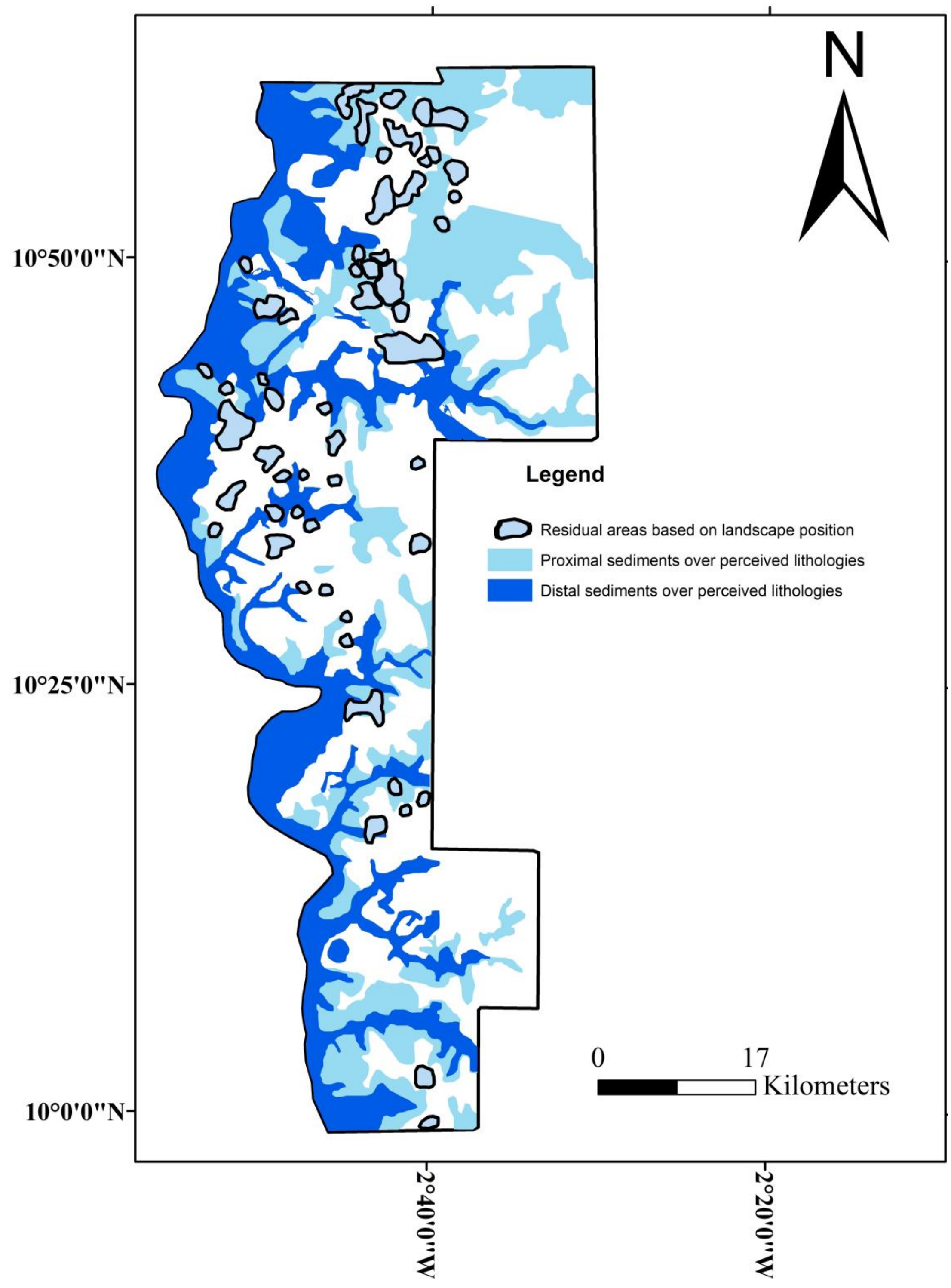

N
10°50'0"N
10°25'0"N
10°0'0"N
2°40'0"W
2°20'0"W
Legend
Residual areas based on landscape position
Proximal sediments over perceived lithologies
Distal sediments over perceived lithologies
0
17
Kilometers

Fig. 5

ACCEPTED MANUSCRIPT

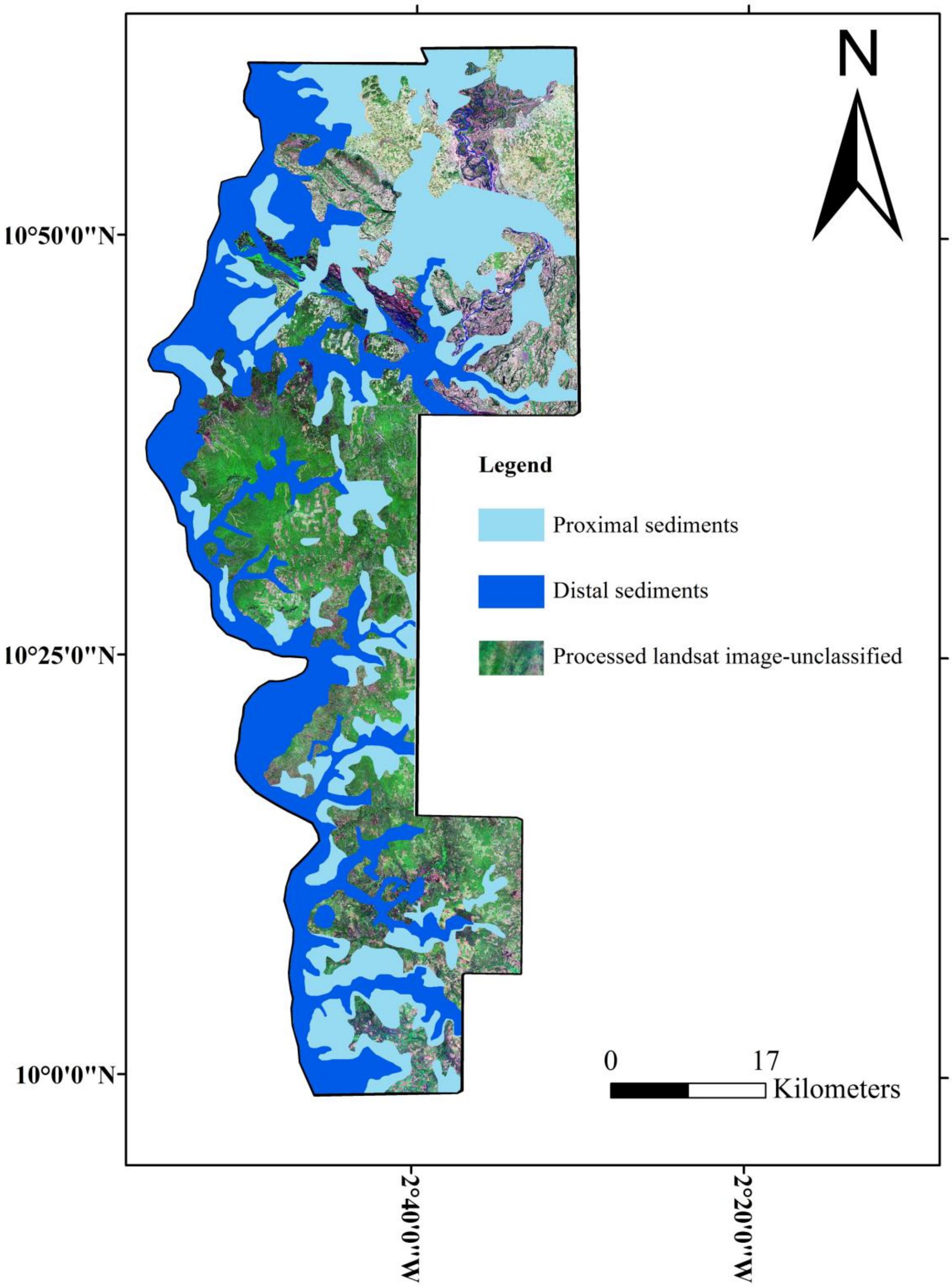


Fig. 6

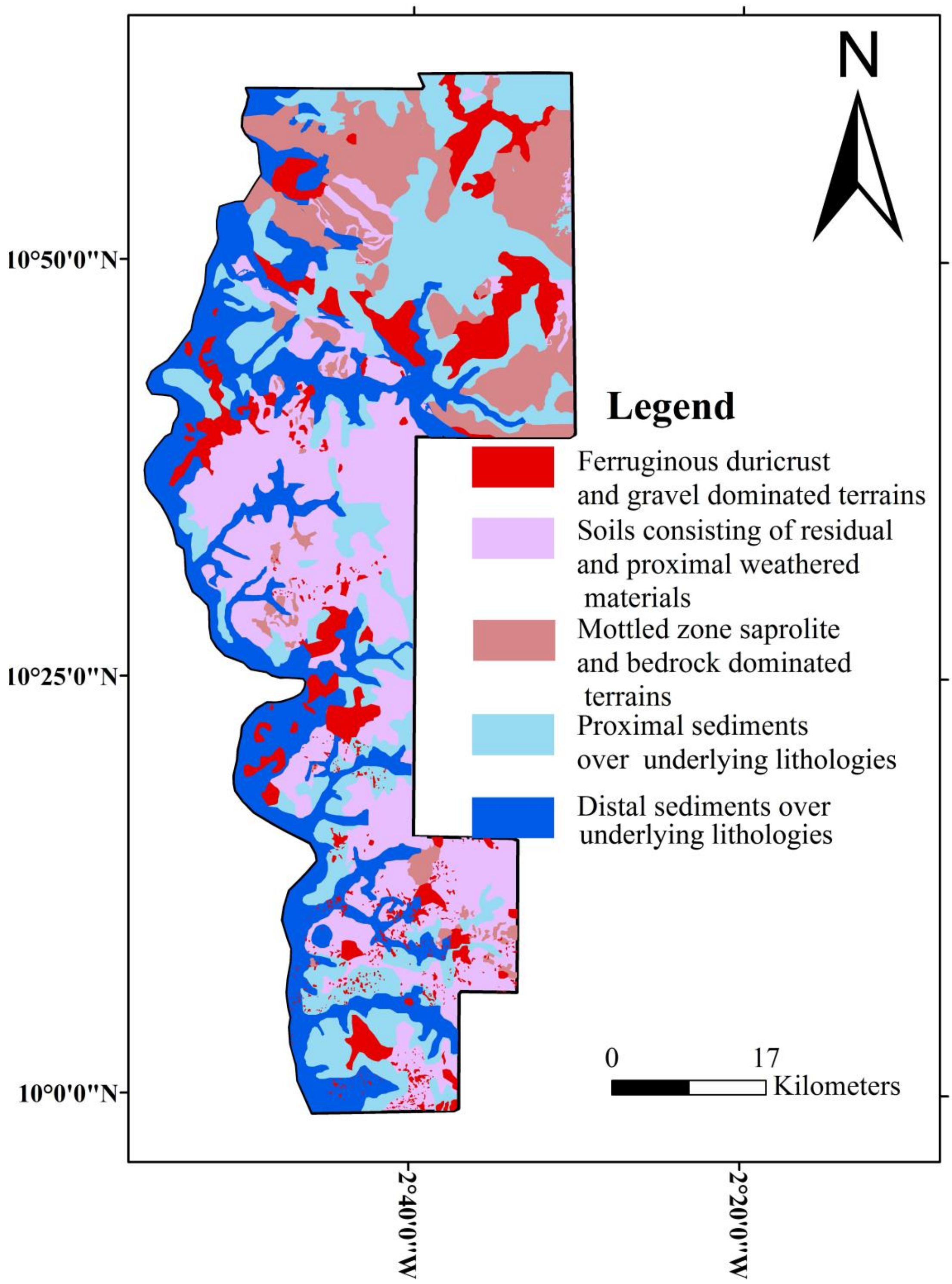
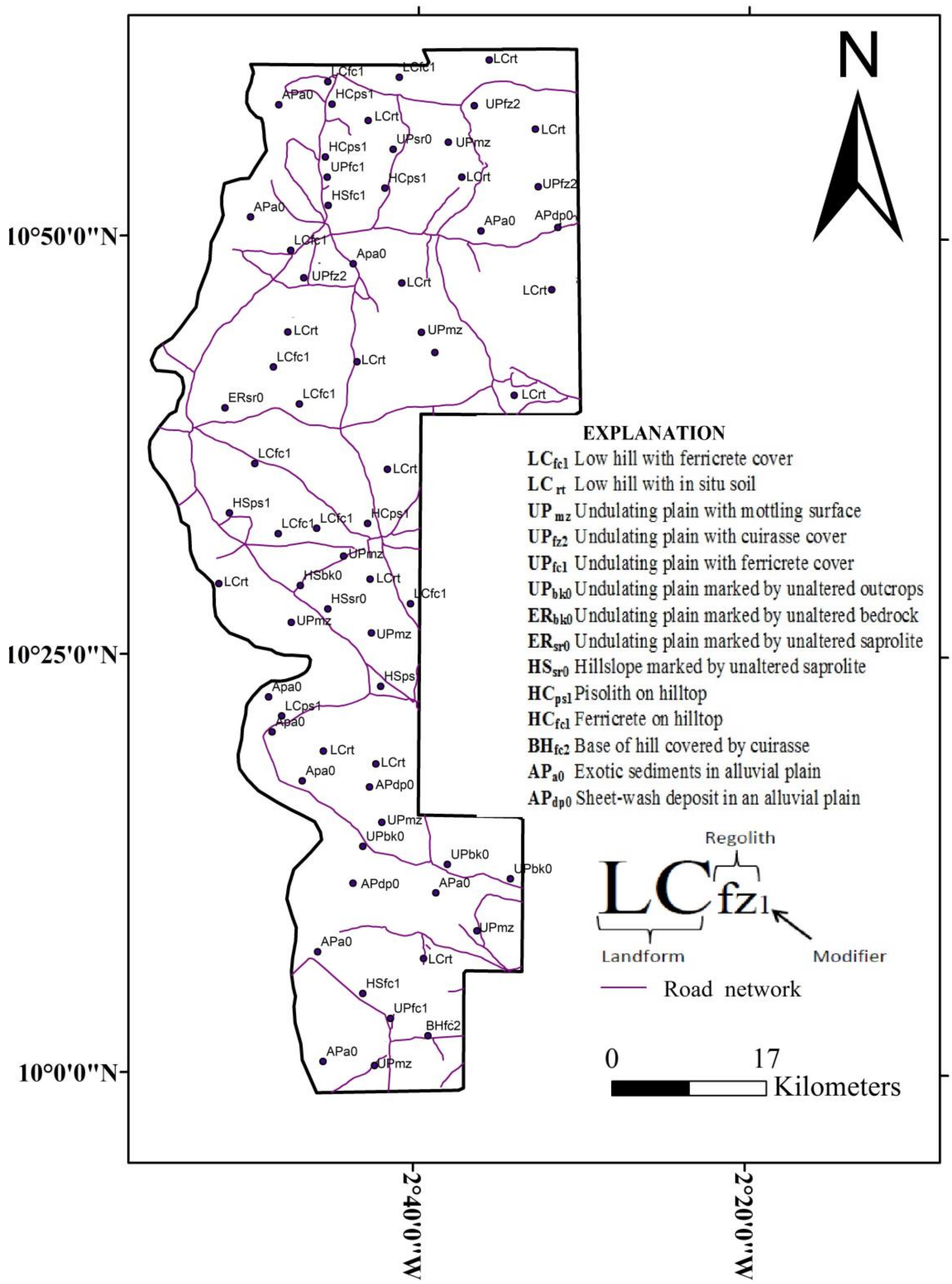

N
Legend
Ferruginous duricrust and gravel dominated terrains
Soils consisting of residual and proximal weathered materials
Mottled zone saprolite and bedrock dominated terrains
Proximal sediments over underlying lithologies
Distal sediments over underlying lithologies
0
17
Kilometers
10°50'0"N
10°25'0"N
10°0'0"N
2°40'0"W
2°20'0"W

Fig. 7



N
10°50'0"N
10°25'0"N
10°0'0"N
2°40'0"W
2°20'0"W
EXPLANATION
LCfc1 Low hill with ferricrete cover
LCrt Low hill with in situ soil
UPmz Undulating plain with mottling surface
UPfz2 Undulating plain with cuirasse cover
UPfc1 Undulating plain with ferricrete cover
UPbk0 Undulating plain marked by unaltered outcrops
ERbk0 Undulating plain marked by unaltered bedrock
ERsr0 Undulating plain marked by unaltered saprolite
HSsr0 Hillslope marked by unaltered saprolite
HCps1 Pisolith on hilltop
HCfc1 Ferricrete on hilltop
BHfc2 Base of hill covered by cuirasse
APa0 Exotic sediments in alluvial plain
APdp0 Sheet-wash deposit in an alluvial plain
Regolith
LCfz1
Landform
Modifier
Road network
0
17
Kilometers

Fig. 8

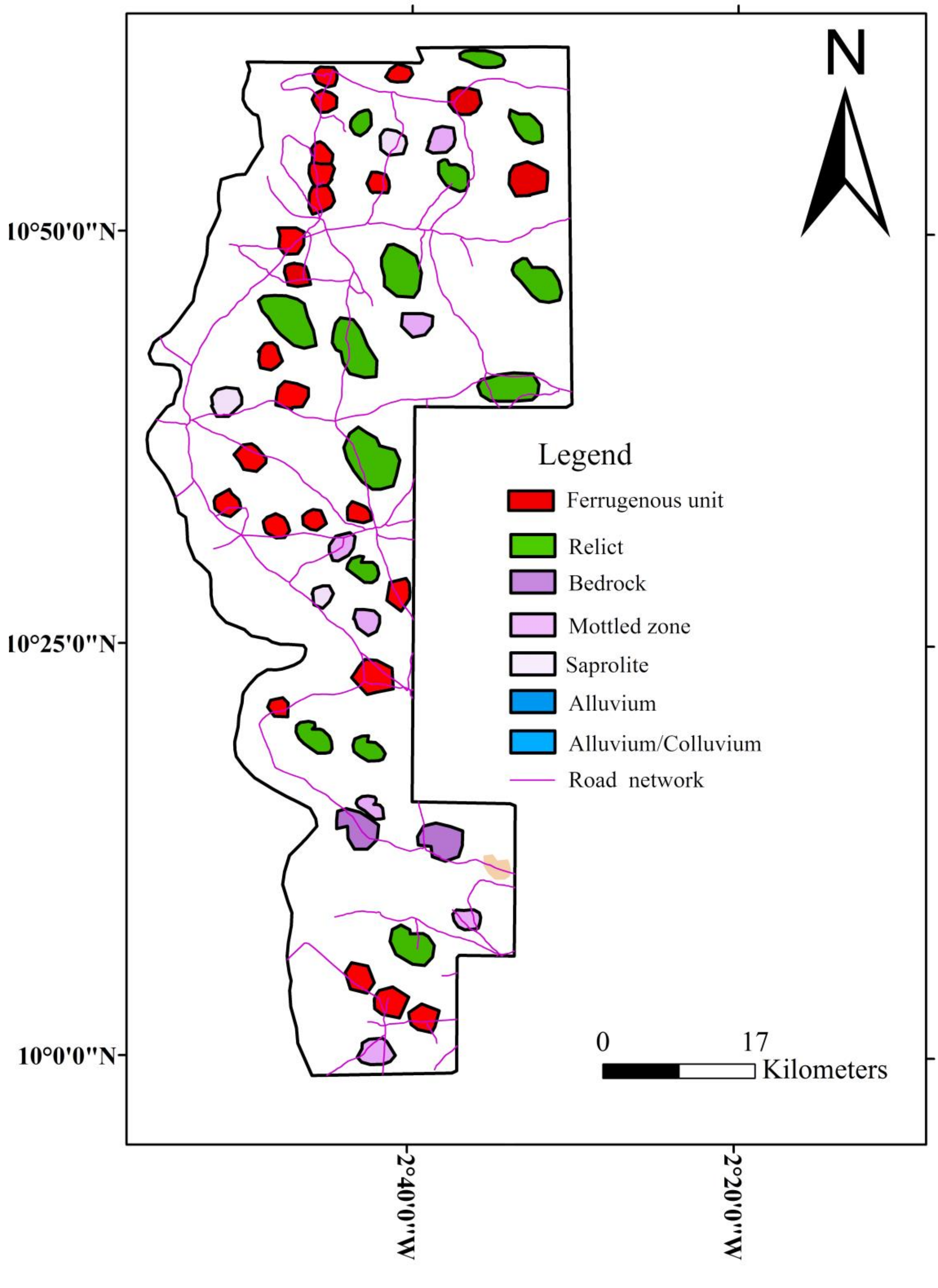

N
Legend
Ferrugenous unit
Relict
Bedrock
Mottled zone
Saprolite
Alluvium
Alluvium/Colluvium
Road network
0
17
Kilometers
10°50'0"N
10°25'0"N
10°0'0"N
2°40'0"W
2°20'0"W

Fig. 9

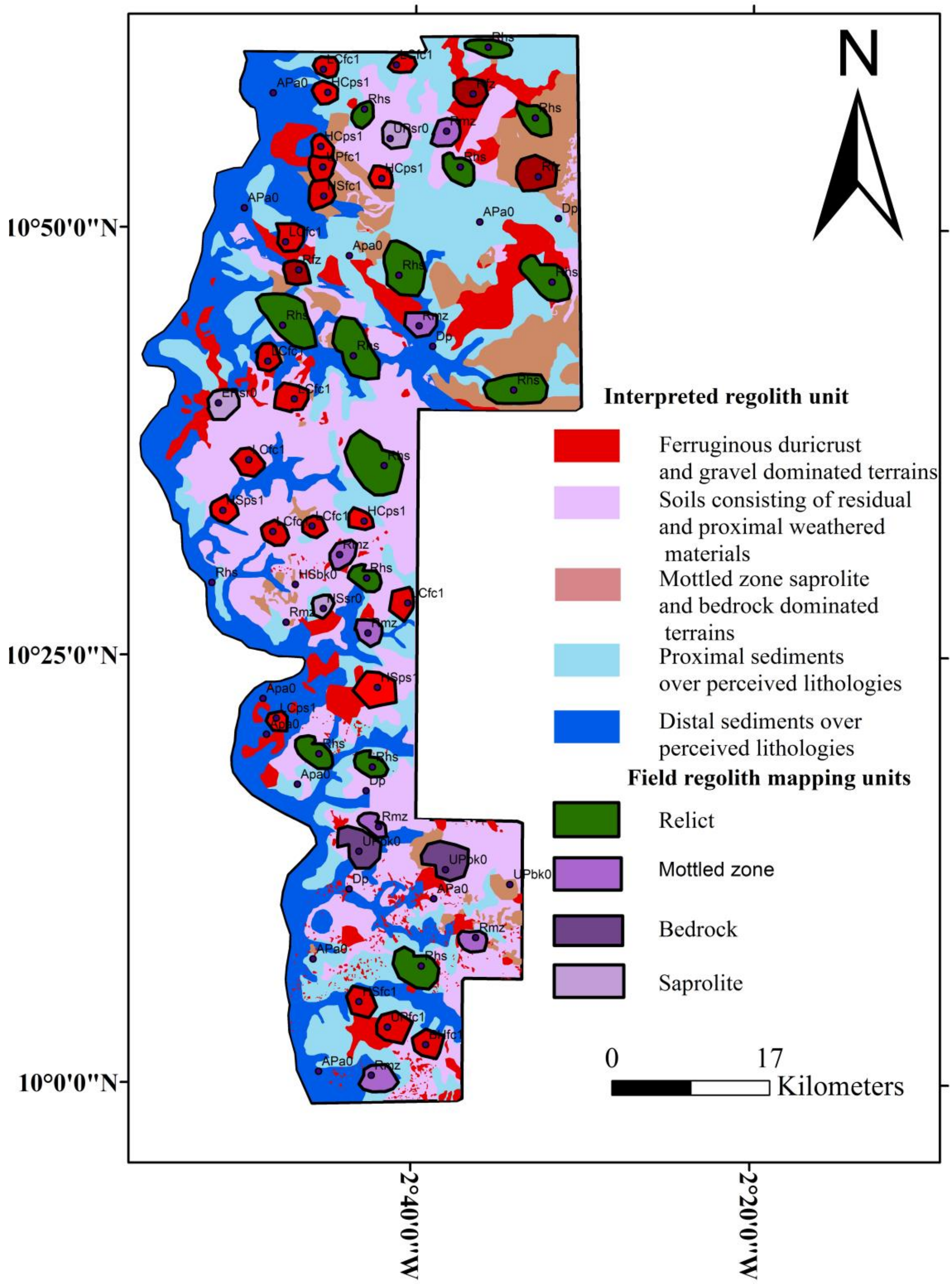

N
Interpreted regolith unit
Ferruginous duricrust
and gravel dominated terrains
Soils consisting of residual
and proximal weathered
materials
Mottled zone saprolite
and bedrock dominated
terrains
Proximal sediments
over perceived lithologies
Distal sediments over
perceived lithologies
Field regolith mapping units
Relict
Mottled zone
Bedrock
Saprolite
0
17
Kilometers
10°50'0"N
10°25'0"N
10°0'0"N
2°40'0"W
2°20'0"W

Fig. 10

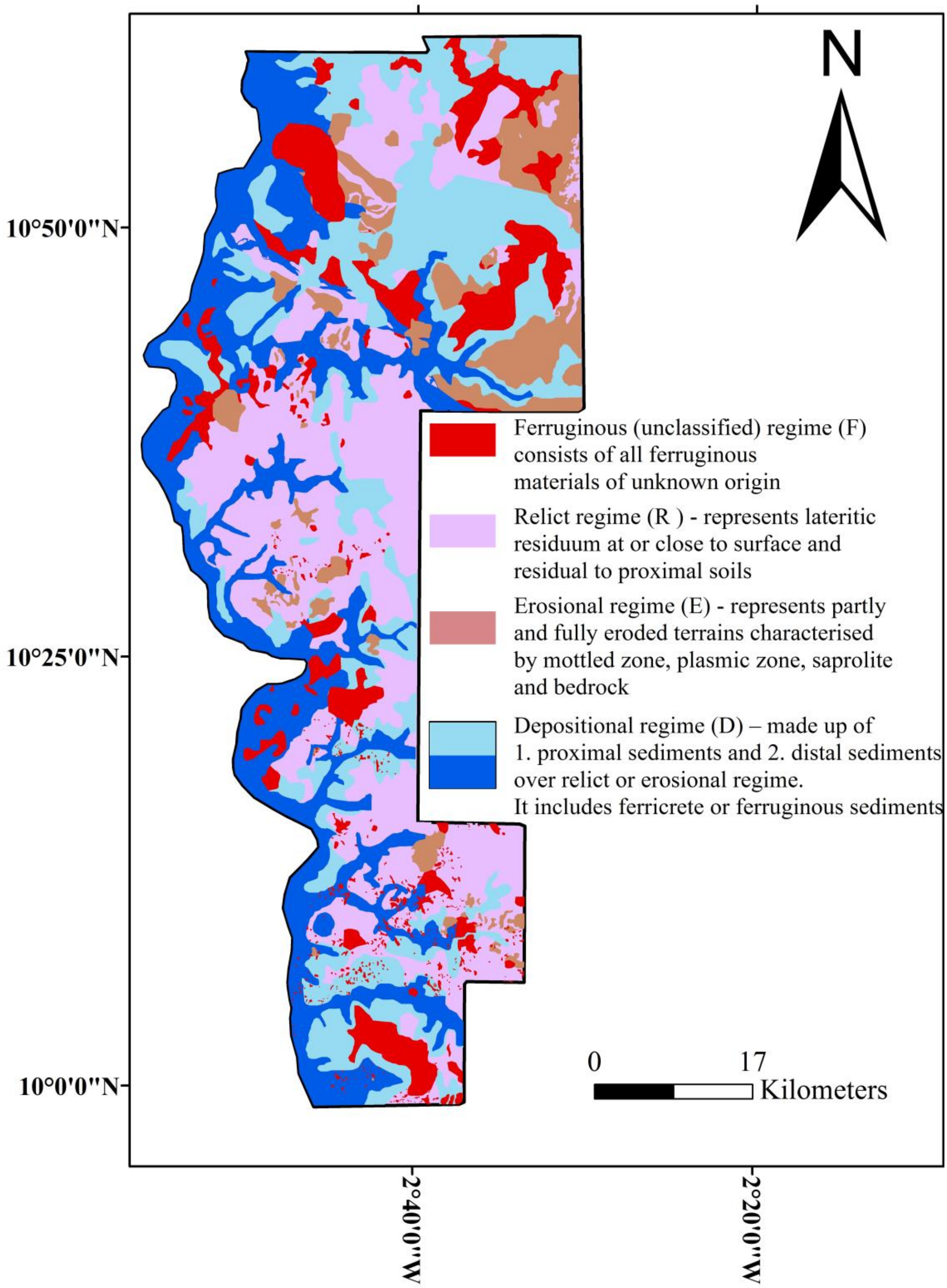

N
10°50'0"N
10°25'0"N
10°0'0"N
2°40'0"W
2°20'0"W
Ferruginous (unclassified) regime (F) consists of all ferruginous materials of unknown origin
Relict regime (R) - represents lateritic residuum at or close to surface and residual to proximal soils
Erosional regime (E) - represents partly and fully eroded terrains characterised by mottled zone, plasmic zone, saprolite and bedrock
Depositional regime (D) – made up of 1. proximal sediments and 2. distal sediments over relict or erosional regime.
It includes ferricrete or ferruginous sediments
0
17
Kilometers

Fig. 11

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Table 1 Types and properties of remote sensing data used (WAXI-IRD internal data base)

Data type	Band No.	Spectra range (µm)	Ground resolution (m)	Bits
Landsat	1	0.45-0.52		Best 8 of 9
	2	0.53-0.61		
	3	0.63-0.69		
	4	0.78-0.90		
	5	1.55-1.75		
	6	10.4-12.5		
Radiometric			1:100000	
SRTM/DEM			90 m pixels	

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LANDFORM TYPE	CODE	REGOLITH TYPE	CODE
Alluvial landform	AL	Ferricrete	fc
Alluvial plain	AP	Cuirasse	fz
Flood plain	AF	Residual soil	rt
Alluvial terrace	AT	Sheet wash deposit	dp
Alluvial swamp	AS	Exotic sediment	a
Erosional landform	ER	Mottle zone	mz
Pediment	EP	Pisolith	ps
Etchplain	EP	Saprolite	sr
Rises	ES	Bedrock	bk
Low hill	LC	Duricrust	dc
Hilltop	HC	Talus	ts
Hillslope	HS	Sand	sd
Base of hill	BH	Clay	cy
Plateau	PT	Silt	st
Undulating plain	UP	Loam	lm

SURFACE MODIFIER

Degree of induration

No	0
Low	1
Medium	2
High	3

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Highlights

- Regolith Landscape map was developed for mineral exploration survey works at the Lawra Belt.
- Remote sensing interpretation and field mapping was helpful approach in regolith map creation.
- Four-step approaches accounting for weathering histories were employed in the field mapping.
- Regolith boundary discrimination was from interpretation of Genetic map and Interpretative map.
- Spatial distributions of the regolith materials were identifiable on the Non-genetic map.
- Correctness of remote sensing interpretation was validated from the Genetic map.

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