GEOCHEMICAL EXPLORATION AND MAPPING IN SRI LANKA: A REVIEW

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ABSTRACT

Geochemical exploration and mapping is a powerful tool that provide valuable multi-user data bases for scientists and planners in diverse sectors including industrial, environmental, agricultural and health. In geochemical exploration, minor and trace element contents are mainly determined in the earth surface materials, those vary with lithology, climate, relief and vegetation etc. using lithogeochemical, soil geochemical, hydrogeochemical, biogeochemical and atmogeochemical methods. Average global element contents in different geological materials, referred as Clarke Values, provide useful general framework for geochemical exploration. Geochemical mapping is widely used in mineral exploration in locating poorly exposed, generally low–grade deposits by systematic measurement of chemical properties of mineral resources and its weathering products by determining anomalies of mineralization.

Applied geochemical work in Sri Lanka was initiated by the Geological Survey Department (GSD) in the early 1960s for Panirandawa and Wilagedara iron ore deposits. An integrated mineral exploration surveys including geochemical exploration has been used by the GSD and its successor, the Geological Survey and Mines Bureau (GSMB), to explore large mineral deposits including Eppawala apatite deposit and Seruwila copper magnetite deposit. Recently, many studies have been conducted on trace element geochemistry of gem sediments to detect important indicators to locate hidden gem beds in southwestern Sri Lanka. Number of geochemical studies has also been conducted on crustal evolution beneath Sri Lanka with special reference to the characterization of isotopic signatures within the tectonically juxtaposed main lithotectonic units. Countrywide Geochemical mapping programme was initiated by the GSMB to establish geochemical background levels of nutrients and toxic elements in soils (Environmental Series) and to identify of possible mineralizations using both regolith and stream sediment data (Exploration Series). Future geochemical exploration surveys need to be focused on multiple perspectives such as sustainable exploitation of mineral resources, environmental monitoring and crustal studies using advances in geochemical exploration technology.

Keywords: Geochemical exploration, Crustal evolution, Mineral exploration, geochemical atlas, Sri Lanka

INTRODUCTION

Geochemical mapping is a valuable tool to extract element distribution patterns from the earth materials such as soils, rocks, stream sediments and plants. The distribution of chemical elements in the earth’s surface materials signals the chemical characteristics of underneath geology that influence on soil fertility, forestry, water quality, human-
academic studies of the upper continental crust.

Geochemical Mapping is widely used in mineral exploration. Today, there is a small chance for a geologist to discover a new ore deposit with the conventional prospecting using hammer, hand lens and compass. In recent decades, many successful exploration techniques have been developed based on highly developing sciences of geochemistry, geophysics and remote sensing. These techniques are very valuable in locating poorly exposed or blind ore deposits particularly of low grade large ore deposits. Geochemical exploration includes systematic measurement of one or more chemical properties of naturally occurring mineral resources and its weathering products by determining anomalies or disturbances which are related to mineralization. Geochemical exploration uses minor and trace elements and with a lesser degree of major elements. Element contents in the earth surface vary with lithology, climate, relief and vegetation etc., and average global element contents in different geological materials, referred as Clarke values, provide useful general framework for geochemical exploration.

Applied geochemical work in Sri Lanka was initiated by the Geological Survey Department (GSD) in the early 1960s with the analysis of Cu, Pb, Zn, U and few other elements using largely colorimetric and chromatographic techniques. Soil samples from the Wilagedara B and Panirandawa iron ore prospects were analyzed for Copper (Cu) mainly to see whether the iron ore bodies could be located as Cu was found to be a trace element in the magnetite of these ore bodies. Trace element studies of the magnetite form Wilagedara deposit has shown 1.2-1.3% MnO, 0.07-0.1% CuO, 0-<0.05% PbO, <0.005% ZnO, traces of Cr2O3 and TiO2 was absent. In contrast, magnetite from the neighbouring rocks show high TiO2 and MnO while CuO, PbO, and ZnO were absent; these results were significant and it was interpreted that the magnetite of Wilagedara B deposit is of metasedimentary origin while magnetite in the country rocks are of a different paragenesis (Siriwardana, 1989). In addition, an important relationship was found between barite and magnetite in the Wilagedara deposit where layers of barite and magnetite are interbanded. Bulk analyses of drillcores have given upto 2% BaO and this was confirmed by the finding of new mineral termed anandite, a barium iron silicate with nearly 20% barium (Ba). A reconnaissance geochemical survey of the part of the Sinharaja Forest Reserve and the neighboring areas was carried out by the GSD in 1964. During this survey number of stream sediments, soil, water and panned concentrates were collected for trace element analysis for heavy mineral prospecting. The study revealed 10-30 ppm Cu and 10-20 ppm Pb were found in soil samples and only significant mineral, monazite which was found to vary 1-2% of total heavy mineral content. Chromatographic techniques did not detect uranium (U) in the water samples. An integrated approach for mineral exploration including a component of geochemical exploration has been used by the GSD and its successor, the Geological Survey and Mines Bureau to explore some significant mineral deposits in Lanka (Fig. 1). For e.g., Integrated geological, geophysical, geochemical and drilling surveys have been conducted for Eppawala Apatite Deposit, Seruwila Copper Magnetite Deposit, Miocene Limestones in the northwest and Sepentinite bodies at Udawalawe and Ussangoda. Apart from integrated surveys carried out to outline configurations of already discovered deposits, stream sediment geochemical studies have been conducted islandwide (e.g., uranium survey in 1979) or in discrete river basins (gem sediment studies) to detect important indicators to locate hidden mineralizations and to discuss their provenance. Geochemical characteristics of isolated mineral prospects such as hydrated iron ore at Delawere were studied recently (Jayawardana et al., 2014). In addition, number of geochemical studies have been conducted since 1980s on understanding crustal evolution beneath Sri Lanka with special reference to isotopic characterization of tectonically juxtaposed main lithotectonic units.

GEOCHEMICAL EXPLORATION METHODS

Geochemical exploration is conducted on a regional scale (up to several thousand sq.
Figure 1. Main mineral commodities for which geochemical exploration was applied in Sri Lanka
kms), local scale (a few sq. kms), a detailed or minor scale (several hectares) and analytical data from this samples may contain two sets of components; 1) background components and 2) anomalous components which are determined by the average or background value and the spread around the value (standard deviation). Background values form the normal geochemical relief from which geochemical exploration tries to identify those anomalous values which deviate from this relief due to the presence of mineralization. Anomalous values do not always imply the presence of a mineralization, which may be true significant anomalies or false insignificant anomalies. Statistics show only about 0.5% of the anomalies ultimately led to the discovery of a new mineral deposit and a comprehensive knowledge of ore deposits, field data, geological and morphological information and experience help to distinguish the significant from non-significant anomalies. Nevertheless follow-up work is required to confirm the non-significance of a certain anomaly, which is always preferable than overlooking a significant anomaly. Behavior of the chemical elements is caused by the properties of the atom (based on the behavior, elements are classified as lithophile, chalcophile, siderophile and atmophile elements) and the external conditions under which the processes (described in geochemical cycle) take place; temperature, pressure, redox potential (Eh) and acidity (pH) etc. The mobility of an element causes a redistribution or dispersion of the element in the form of a halo or aureole around the mineralization. This aureole is generally much larger than the high concentration zone itself and is, therefore, easier (with less samples) to be discovered by geochemical techniques. Primary haloes are formed contemporaneous with the emplacement of the ore body (syngenetic), commonly in deep-seated environment whereas the secondary haloes are formed by later epigenetic processes (after the formation of the mineralization), that alter the element distribution at or near surface often caused by chemical and mechanical weathering processes. Metals are extracted from mineral deposits specifically mined the metal (i.e. gold) or from a great variety of polymetallic deposits in which it is a minor by-product. Therefore, certain metals such as gold are considered as indicators of its own deposits but also of a large number of other types containing mainly copper, silver, lead and zinc. Outside the ore forming element itself, the dispersion of so-called indicator or pathfinder elements can be used to trace a deposit. For e.g., dispersion of arsenic (As) in the weathering environment of a gold-sulphide deposit will be much larger and therefore, easier to detect with a lower sample density than the dispersion pattern for gold itself. The main geochemical methods used in the exploration for ore deposits are discussed below.

**LITHOGEOCHEMICAL METHODS**

These methods essentially deal with the use of rocks as the medium for geochemical exploration. Rock chip sampling is effective in delineating geochemical anomalies associated with outcropping or sub-cropping deposits. Sr/Y ratios in whole rock samples can be used to define fertile oxidized hydrous melts, and oxygen isotopes have been used to define fluid flow pathways at the Comstock epithermal gold deposit, USA (Robert et al., 2007). Igneous rocks, have been the target for lithogeochemical techniques as many deposits particularly of hydrothermal and polymetallic types are genetically related to such rocks. Apatite fission track studies have outlined large thermal aureoles are related to Carlin-type deposits. Igneous suites and alteration zones of favorable age can now be more rapidly and economically identified with new dating techniques.

**SOIL (PEDO-) GEOCHEMICAL METHODS**

Soils, weathered residuum, calcrete, silcrete, ferricrete and various glacial materials including till, sand, gravel etc. include the material used in soil (pedo-) geochemical surveys. Soil formation depends largely on reduction-oxidation potential and microbial populations in soil, soil gas analysis, selective leaches, halogen concentrations, and isotopic
compositions are relatively new techniques particularly used in gold exploration (Robert et al., 2007). Analysis of these materials directly for the metal or its pathfinders or be panned and a heavy (light) concentrate obtained for mineralogical and or chemical analyses. In some case studies, arsenic in residual soils showed a direct relationship to gold-arsenic mineralization and potential gold-bearing areas were delineated (Dissanayake, 1985) Gold from the bed rock was accumulated by pine and aspen trees were concentrated in humus-rich forest soil (mull) by the decay of organic litter from trees (Curtin et al., 1968; Dissanayake, 1985).

HYDROGEOCHEMICAL METHODS

The hydrogeochemical methods include sampling and analyses of ground and surface waters, streams (active and dried –up), rivers, lakes, swamps, old river terraces and their sediments. As element concentrations in natural waters are very low, the analyses of water alone present certain technical difficulties. Sediments, however, have been extensively used in geochemical exploration. Fischer and Fisher (1968) studied panned concentrate analyses of stream sediments in the geochemical exploration for gold observed that a few samples from streams are adequate to distinguish between “barren” and “mineralized” areas and to determine the relative amount of gold in mineralized areas.

BIOGEOCHEMICAL METHODS

Basic idea of biogeochemistry is that plants (and animals) are able to take up and concentrate trace metals from weathered rocks and soils. Plants, animals and their fossil residues are often used as sampling media in the exploration for minerals. In general, the gold contents of flora tend to exceed the norm by a factor of 2 or more in the vicinity of gold deposits (Dissanayake, 1985). For such surveys, homogenous vegetation is required and it is sometimes hard to determine which part of the plant has to be sampled. The sampled material has to be ashed and large amount of plant material is needed to concentrate the trace elements to a detectable level. This will, however, eliminate the application of these methods for the volatile elements such as Hg, As, Sb and Pb.

ATMOGEOCHEMICAL METHODS

It has been noted that mineral deposits are formed at fissures in the earth where warm exhalations emanate. Even though, some elements like gold is not known to form common naturally occurring inorganic volatile compounds, it does form a number of organic compounds including alkyls, organo-arsenic compounds and chelates some of which have a high volatility. Gasses move to lower pressure and hence from depth to surface and some gasses are characteristic for certain forms of mineralization. Most wide application after radon gas in uranium exploration is probably the use of mercury gas which is being freed from weathering sulphide deposits.

APPLIED GEOCHEMICAL WORK ON MINERAL EXPLORATION IN SRI LANKA

GEOCHEMICAL STUDIES OF THE EPPAWALA APATITE DEPOSIT

The Eppawala apatite deposit was discovered by the GSD during systematic geological mapping in 1971 and detailed exploration program was conducted during the period 1971-1976. Jayawardena (1976) placed a major emphasis on the geochemistry of apatite in the Eppawala apatite deposit in the only detailed publication available on the geological aspects of deposit. The geochemistry of samples were studied by Dr. T. Jones of the Institute of Geosciences, U.K., who was a world authority on carbonatite analysis from the African Continent (Jayawardana, 1986). Eppawala apatite deposit consists of two main apatite bearing phases, namely a coarsely crystalline chloro-apatite of variable Cl: F ratio and a crypto-crystalline carbonate apatite of the francolite variety which is interstitial cementing material in the rock. International Fertilizer
Development Center (IFDC) and the Geological Survey Department (GSD) of Sri Lanka have analyzed the leached ore (primary apatite + matrix) reporting 36.0 to 40.0 % P$_2$O$_5$ with high amounts of impurities. The REE fractionation of Eppawala rocks is pronounced, and La/Yb ratios vary between 14 and 43; both apatite and calcite show markedly elevated strontium levels ($\leq$0.6%) (Pitawala et al., 2003). The markedly increased REE concentrations in the bulk chemistry of the rocks have been shown to be mainly controlled by the content of phosphate minerals; compared to most carbonatites, the Eppawala rocks are generally depleted in selected trace elements, particularly Ba, Nb, Th, V, U and Zr and this depletion may be due to either a primary infertility of the parent magma with regard to such trace elements, or it is a result of fractional crystallization during the rock formation (Pitawala et al., 2003). The main drawback in utilizing this valuable mineral resource for manufacture of water soluble phosphate fertilizer by converting into phosphoric acid is the high chloride content (av. 1.0 per cent) and the high iron and aluminum oxide contents (Fe$_2$O$_3$ + Al$_2$O$_3$ = 8 per cent); the industry standards for phosphate rock in the manufacture of intermediary phosphoric acid are 0.05 per cent chloride and 5 per cent Fe$_2$O$_3$ + Al$_2$O$_3$ (Jayawardana, 1986).

The geology, geochemistry, engineering and agronomic aspects of the Eppawala apatite deposit have also been studied by many scientists of various disciplines (Dahanayake and Subasinghe, 1988, 1989a&b, 1990a&b, 1991, Gunawardena and Glasser, 1979; Amerasekera et al., 1979; Sivasubramaniam et al., 1981; Gunawardena, 1982; Amerasekera and Ismail, 1983; Weeraratne, 1983; Gunawardena and Annersten, 1987; Tazaki et al., 1987; Gunawardena, 1987; Tennakone, 1988; Tannakone et al., 1988, Pitawala et al., 2003, Dissanayake and Chandrajith, 2009).

**GEOCHEMICAL EXPLORATION FOR SERUWILA COPPER- MAGNETITE DEPOSIT**

The copper-magnetite deposit located at Seruwila, Northeastern Sri Lanka is the first base metal find in the country and was discovered in 1971 by the Geological Survey Department of Sri Lanka (GSD). Subsequently, large scale geological mapping, ground magnetometer reconnaissance and detailed surveys were carried out on the prospect by Jayawardana (1982). These investigations indicated the existence of mineralized bodies trending NE-SW and parallel to the regional strike. For detailed exploration work, the mineralized area was divided into three targets namely, Arippu, Block C and Kollankulam. A geochemical study, which included a soil survey along geophysical grid lines, was initiated in 1976. This was abandoned later as the area was found to be highly disturbed due to past mining and agricultural activities. However, sample analyses using direct reading emission spectrometry ("quantometer") showed that the Cu and to a lesser extent Zn occur in anomalous concentrations while Mo, Zr, Mn, Pb, Y, Bi, Sr, V, Cr, Ni and Co show relatively high concentrations.

**GEOCHEMICAL EXPLORATION PROGRAM FOR URANIUM**

Large parts of Sri Lanka have a terrain favorable for geochemical reconnaissance surveys, particularly for stream sediment surveys. However, very little geochemical exploration work has been done in early days covering the entire island, except for Stream sediment geochemical exploration program initiated by the GSD with the assistance from International Atomic Energy Authority (IAEA) in 1979 for detection of U and base metals.

The programme initiated with a preliminary survey where about 900 sample points were planned on the basis of watershed boundaries with the average sample density of one sample per sixty nine sq. km (Siriwardana, 1989). The samples collected during the preliminary survey were analyzed for leachable uranium by florometry. Considering 4 ppm and 10 ppm U as threshold values for bulk stream sediments and panned concentrates respectively, 4 discrete geographic areas were identified as anomalous areas (Siriwardana, 1989). These were;

1. Rakwana Group (Ratnapura, Aluthgama, Rakwana, Timbloketiya and Ambalantota topographic sheets)
2. Mahaweli-Mahaoya-Kalmunai Group
(Mahaoya, Kalmunai, Hanguranketha and Nilgala topographic sheets)

3. Arugam Group (Passara, Potuwil and Buttala topographic sheets)

4. Kalaoya Group (Kalaoya and Galgamuwa topographic sheets)

Follow up work in the 1 and 2 areas began in 1980 and continued till 1983. Sampling density in the follow up phase was approximately one sample per 2 to 5 sq. km. Number of samples from Maha Oya area had Uranium values greater than 500 ppm. After the preliminary and follow up phases, 9 areas were identified for detailed geochemical sampling. These areas include:

1. Kala Oya
2. Galgamuwa
3. Polonnaruwa
4. Maha Oya
5. Kalmunai
6. Passara
7. Pottuvil
8. Rakwana
9. Udawalawe

The exploration carried out delineated areas 1 and 4 as targets for further exploration. Except for the Kala Oya area, rest of the eight areas are mainly composed of highly metamorphosed rocks. In Kala Oya area, sedimentary rocks of Jurassic age (shales and arkose sandstones) are identified. Approximate alignment of anomalous locations of area 4 suggested that the U mineralization likely to be concentrated in lineaments such as faults and joints. Detailed surveys to assess the U potential in these areas are in progress.

GEOCHEMICAL STUDIES ON GEM SEDIMENTS

Since 1980s, much attention has been focused on the investigation of the geochemistry of the gem sediments and some of the rivers draining the gem fields (Rupasinghe and Dissanayake, 1984; Dissanayake and Rupasinghe, 1986; Dissanayake et al., 1994, 2001; Chandrajith et al., 2000a, 2000b, 2000c, 2001). As Sri Lanka has a well-marked radial drainage system and all gem deposits are located within the Highland Complex, stream sediment geochemistry is an ideal tool for the study of gem deposits (Dissanayake et al., 2001). Fernando et al. (1996) developed a geochemical and statistical method to delineate areas that do not have a potential to bear gems from those known to bear gems in Sri Lanka. Some surveys for trace element geochemistry and heavy mineral distribution of gem sediments have conducted to detect important indicators to locate hidden gem beds in southwestern part of Sri Lanka. Dissanayake et al. (2001) reviewed the stream sediment geochemistry of some gem deposits with a particular emphasis on Ratnapura, Elahera and Walawe Ganga Gem fields. They showed that fine fraction of the gem alluvium in the Ratnapura and Elahera Gem fields Be and Zr are enriched while most alkalies and alkaline earths are depleted.

GEOCHEMICAL STUDIES ON CRUSTAL EVOLUTION OF SRI LANKA

Early geochemical studies on the crustal evolution of the high-grade gneisses of Sri Lanka were mainly based on Rb-Sr whole-rock data of Crawford and Oliver (1969). The ideas broadly summarized by Perera (2016) are given below (Comparative nomenclature for main rock units in the Precambrian basement of Sri Lanka is given in Kroner et al., 1991).

(a) The Vijayan Complex (VC) and the Wanni Complex (WC) are retrogressed equivalents of the Highland Complex (Cooray, 1961, Hapuarachchi, 1975).

(b) VC and WC formed a basement for the HC (Katz, 1971)

(c) HC formed as a sedimentary basin between two crustal plates, the VC and WC (Munasinghe and Dissanayake, 1982).

Recent isotopic studies of the age of the crust in Sri Lanka and its high grade metamorphism show a clear and consistent picture of the crustal evolution, which forces to revise much of the interpretation of earlier geochronological data yielding Rb-Sr ages (Hofmann, 1991). Based on Nd-model ages, the Precambrian basement is divided into three major lithotectonic units (HC, WC and VC); Intensely deformed granulite grade supracrustals and granitoids of HC display an extended crustal history (2-3 Ga) whereas WC is characterized by orthogneisses, granitoids and subordinate metasediments with younger Nd-model ages (1-2 Ga) and the boundary between
these two units is not sharply defined by the model ages; On the east, VC rocks, mainly I-type granitoids, border the HC with younger Nd-model ages (1-2 Ga) (Milisenda et al. 1988; Cooray et al.1994). Pohl and Emmermann (1991) studied the chemical composition of the Sri Lankan basement to reveal that most of the rocks are of magmatic origin assigned to three main groups; bimodal basalt-rhyolite association (Highland-Southwestern Complex), a calc-alkaline series (amphibolites to granulite grade orthogneisses exposed in the Kadugannawa Complex and granitic to tonalitic I–type gneisses of VC) and alkaline rocks (granitic to syenitic, late to post tectonic granitoids exposed in southwestern WC; these alkaline rocks show pronounced enrichments in Na₂O, K₂O, P₂O₅, Zr, Pb, Th, Sr, Ba and REE with strongly fractionated patterns from LREE to HREE. Eppawala “apatite marble” displays extremely high contents of LREE and therefore, interpreted as metacarbonate. (Pohl and Emmermann, 1991).

GSD Professional Paper NO. 5, The crystalline crust of Sri Lanka, Part1, Summary of Research of the German-Sri Lankan Consortium was published in 1991 with 19 Papers, (edited by A. Kroner) elaborating a comprehensive account on geochemistry, geochronology, carbon and oxygen isotope ratios and metamorphism of Precambrian basement of Sri Lanka with particular emphasis on mafic intrusions of Kandy area, charnockite formation and southwestern pelitic granulites. In addition, since 1980s, number of studies have significantly contributed on geochemical and isotopic characterization of Sri Lankan Precambrian crust which include, Baur et al., 1991; Cordani and Cooray, 1989; Dharmapriya et al., 2014; Dissanayake and Chandrajith, 1999; Hansen et al., 1984 and 1987; Hapuarachchi 1988; Hiroi et al., 1987; Jayawardana et al., 2014; Kehelpannala, 2003 and 2004; Kriegsmann, 1994; Kroner et al., 2003 and 2013; Mathavan et al., 1990; Mathavan and Fernando 2001; Perer, 1984; Prame 1991 and Vitanage, 1985

Recently, Malaviarachchi and Dharmapriya (2014) studied geochemistry of PGE and gold in magnesio-calcic granulites of central HC to show that high magnesio-calcic granulites (HMC) have low overall REE abundances compared to low magnesio-calcic granulites (LMC) and PGE and Au show a systematic positive correlation with increasing MgO contents. In a recent mineral chemistry and petrology study of charnockitic granulites and calc silicate rocks of southern HC, Prame (1997) discussed the geochemistry and genesis of granitoid rocks from Southern Sri Lanka which are mostly tholeiitic, meta-aluminous and mainly A-type granites characterized by high K₂O/Na₂O, FeO/MgO and high Zr, Nb and LREE contents, most belonging to the relatively Ce- and Y-enriched A₂-type. Prame and Ajith Prama (2014) constrained P-T conditions of granulite grade metamorphism and characteristics of fluid regime. According to Dharmapriya et al. (2015), petrological and U–Pb zircon geochronological data on a suite of ultrahigh-temperature (UHT) metapelites and mafic granulate from the HC in central Sri Lanka which provide convincing evidence for Late Neoproterozoic UHT metamorphism. The appearance of coeval Granulite-grade UHT metamorphic (G-UHTM) belts in the rock record registers contemporary sites of high heat flow, inferred to be similar to modern arcs, abd backarcs, or orogenic hinterlands, where more extreme temperatures were imposed on crustal rocks than previously recorded (Brown, 2008).

According to Perera (2016), retrogression models of HC to form VC and WC, and Plate Tectonic model of Munasinghe and Dissanayake (1982) did not find support in Nd-model ages as HC model ages are older (2.0-3.2 Ga) than VC & WC model ages (1.0-2.0 Ga). Crustal processes like metamorphism cannot account for the near 1.0 Ga age difference between HC & WC/VC Nd-modal ages. HC preserved crust formation ages of 2.0-3.2 Ga; its meta-sediments derived detritus from 2.0-3.2 Ga sources. VC, WC and KC preserved crust formation ages of 1.0-2.0 Ga; metasediments of the WC and VC derived detritus from terrains ≤ 1.0 Ga. The amalgamation of units during tectonics around 600-550 Ma; led to multiple deformation and granulite- to amphibolite-facies metamorphism.

Recent detailed Sm-Nd and Rb-Sr isotopic studies of the high-grade gneisses (Perera and Kagami, 2011; Perera, 2016) suggest that,

(a) Nd-model ages and U-Pb zircon ages do not necessarily represent crust formation ages
and zircon crystallization ages of the orthogneisses due to incomplete isotopic resetting.

(b) Their isotopic composition is unusual as indicated by extremely positive initial εNd (+7.6 at 2800 Ma) of HC orthogneisses

(c) Isochron translation to be used to map interacted crust-mantle volume and estimate its isotopic composition to resolve relations between HC, VC and WC and explain how a range of Nd-model ages from 1.1-3.2 Ga was produced during a long period of crustal residence of Sri Lankan high-grade gneisses.

COUNTRYWIDE SOIL GEOCHEMICAL MAPPING PROGRAM

Countrywide Geochemical Mapping Programme of Sri Lanka was initiated by the Geological Survey & Mines Bureau of Sri Lanka with the objectives of establishing geochemical background levels of nutrients and toxic elements in soils and identification of possible mineralizations; for these purposes two map series are to be published based on 1:100,000 geological map sheet series of the country. Environmental Series is based on surface soil data and Exploration Series will be based on both regolith and stream sediment data (Ranasinghe et al., 2016). Pilot study of the geochemical mapping program was launched in 2009 by selecting a few map sheets for initial sampling. Maps are to be published in the form of Atlases each covering an approximate area of 3500-5000 km² corresponding to 1:100 000 geological maps.

RAKWANA – TANGALLA ENVIRONMENTAL SERIES – SOIL (SHEET 20)

This is the first atlas published under the Environmental Series and it is a result of combined effort of a group of geologists, chemists, technical officers and other laboratory personnel. Rakwana – Tangalla Environmental, Series Sheet 20 shows the nutrients and toxic element levels in surface soil of the area covered by Rakwana, Timbolketiya, Morawaka, Hambantota, Matara, and Tangalla 1:50,000 maps (Fig. 2). This 1:300,000 scale geochemical atlas contains maps depicting distribution of Mg, K, Ca, Fe, Mn, Zn, Cu, Ni, Mo, Se, Cr, Pb, As, Hg, and Cd (Ranasinghe et al., 2016). Sampling of Rakwana, Timbolketiya, Hambantota and Morawaka Sheets were done at each 1 km² area and the adjacent four samples in 1 km² grids were composited for analysis. Matara and Tangalla sheets were sampled at 4 km² intervals. Two samples were collected from each sampling point, the first sample within the uppermost 0.5 m surface layer below the organic layer and the second from 1.5-2 m depth (typically from B-horizon) using both manual and power auguring. The samples from upper layer were used for the preparation of this atlas containing Environmental Geochemical Map Series. Aqua Regia extractable contents of fifteen (15) elements namely, magnesium (Mg), potassium (K), calcium (Ca), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), nickel (Ni), molybdenum (Mo), selenium (Se), chromium (Cr), lead (Pb), arsenic (As), mercury (Hg) and cadmium (Cd) in 1200 surface layer soil samples collected from the Rakwana-Tangalla 1:100,000 Geology Map (Provisional Map Series) have been determined (Table 1). Summary of the element concentrations in the Sheet area is given in Table 2. Ranasinghe et al. (2016) attempted to describe broadly the spatial distribution of element concentrations in terms of litho-chemistry, climate-zonation and soil type. Mg, K, Ca and Mn contents increase from the Wet Zone via Intermediate Zone to Dry Zone, reflecting efficient leaching and mobility with higher rainfall; Relative depletion of K in the Wet Zone, especially in areas with values <0.1% has to be looked in as bioavailability of K is usually between 0.1% and 2% of total K (Ranasinghe et al., 2016) (Fig. 3). According to Ranasinghe et al., 2016, the highest K values are recorded in the Walawe Ganga basin within the Vijayan Complex as well as the Dry Zone. The highest Fe concentration is recorded in the Sinharaja Basic zone and generally high Fe values are displayed within the Highland Complex areas falling within the Wet Zone (Fig. 4); the distribution pattern of Fe can be attributed to lithochemical
Table 1. Details of sample collection in relevant topographic sheets for Rakwana – Tangalla (1:100,000) Sheet area (from Ranasinghe et al. 2016)

<table>
<thead>
<tr>
<th>1:50 000 sheet</th>
<th>Number of samples collected</th>
<th>Number of samples Analysed</th>
<th>Selection criteria of sampling points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timbolketiya</td>
<td>558</td>
<td>212</td>
<td>Sampling points were selected in the middle of 1km<em>1km grids and composited 4 samples into one to make final sample in 4km</em>4 km grid</td>
</tr>
<tr>
<td>Morawaka</td>
<td>935</td>
<td>256</td>
<td></td>
</tr>
<tr>
<td>Hambantota</td>
<td>988</td>
<td>242</td>
<td></td>
</tr>
<tr>
<td>Rakwana</td>
<td>234</td>
<td>234</td>
<td>Sampling points were selected in the middle of 4km*4km grid</td>
</tr>
</tbody>
</table>

characteristics as well as climatic conditions; Reddish Brown Earth Soils (RBE) have higher Mg, Ca and Mn contents compared with Red Yellow Podzolic Soils (RYP) and K and Fe have the reverse relationship (Ranasinghe et al., 2016). Distribution of Pb in soil well demarcates the Highland Complex (HC) - Vijayan Complex (VC) boundary and Ranna Unit and hence seems to mimic the pattern of lithological units. In view of low Se contents in most parts of the Dry and Intermediate zones and low bioavailability of Se, study of crops grown in this area for Se deficiency is warranted. Higher concentrations of Cr in some parts of the Wet Zone, particularly in the area of Sinharaja basic zone are significant (Ranasinghe et al., 2016).

FUTURE STUDIES

Geochemical mapping program initiated by the Geological Survey & Mines Bureau will be continued to complete the entire islandwide coverage of 21 geological map sheets (1:100,000 scale). This will provide a good background dataset for future studies on contamination due to urbanization and industrialization. Although the actual causes of certain health issues such as Chronic Kidney Disease of Uncertain etiology (CKDu) are hitherto unknown, World Health Organization reports have indicated a possible

Figure 2 Index map showing the Sheet 20 Geochemical map area (from Ranasinghe et al. 2016)
link between heavy metals in fertiliser/agrochemicals and the prevalent in the dry zone of Sri Lanka (Ratnayake and Nawarathna, 2014). Therefore, further studies on rare earth and heavy metal impurities in phosphates and other fertilizers and agrochemicals used are a timely need. Scientists have shown that the country's known mineral reserves such as gemstones, phosphates will be depleted in 50 years and the base reserves will be exhausted in 150 years. It was also shown that country has a potential for the discovery of certain mineral deposits such as gold (Ajith Prema et al. 2014). Therefore, future geochemical exploration surveys need to be focused on sustainable exploitation of our mineral resources using advances in geochemical exploration technology.

**Table 2. Summary of the element concentrations in Rakwana – Tangalla (1: 100,000) Sheet area (from Ranasinghe et al. 2016)**

<table>
<thead>
<tr>
<th>Element</th>
<th>Mean</th>
<th>Stdev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg (%)</td>
<td>0.17</td>
<td>0.17</td>
<td>0.00</td>
<td>1.94</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.20</td>
<td>0.16</td>
<td>0.00</td>
<td>0.83</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.17</td>
<td>0.55</td>
<td>0.00</td>
<td>14.63</td>
</tr>
<tr>
<td>Fe (%)</td>
<td>4.65</td>
<td>2.00</td>
<td>0.62</td>
<td>16.53</td>
</tr>
<tr>
<td>Mn (ppm)</td>
<td>543</td>
<td>396</td>
<td>7</td>
<td>3298</td>
</tr>
<tr>
<td>Zn (ppm)</td>
<td>55</td>
<td>30</td>
<td>7</td>
<td>293</td>
</tr>
<tr>
<td>Cu (ppm)</td>
<td>28</td>
<td>15</td>
<td>2</td>
<td>111</td>
</tr>
<tr>
<td>Ni (ppm)</td>
<td>26</td>
<td>36</td>
<td>1</td>
<td>1027</td>
</tr>
<tr>
<td>Mo (ppb)</td>
<td>932</td>
<td>2173</td>
<td>1</td>
<td>56275</td>
</tr>
<tr>
<td>Se (ppb)</td>
<td>247</td>
<td>289</td>
<td>0</td>
<td>2630</td>
</tr>
<tr>
<td>Cr (ppm)</td>
<td>75</td>
<td>60</td>
<td>1</td>
<td>921</td>
</tr>
<tr>
<td>Pb (ppm)</td>
<td>16</td>
<td>12</td>
<td>1</td>
<td>114</td>
</tr>
<tr>
<td>As (ppm)</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Hg (ppb)</td>
<td>59</td>
<td>76</td>
<td>0</td>
<td>868</td>
</tr>
<tr>
<td>Cd (ppb)</td>
<td>65</td>
<td>61</td>
<td>1</td>
<td>343</td>
</tr>
</tbody>
</table>
Figure 3. Map showing distribution of potassium (K) in soil in Sheet 20 area (from Ranasinghe et al. 2016)

Figure 4. Map showing distribution of iron (Fe) in soil in Sheet 20 area (from Ranasinghe et al. 2016)
CONCLUSIONS

Despite being a powerful tool that provide valuable multi-user data bases for scientists and planners in diverse sectors including industrial, environmental, agricultural and health, hitherto, geochemical exploration and mapping has had limited application in Sri Lanka. Applied geochemical work in Sri Lanka was initiated by the Geological Survey Department (GSD) in the early 1960s for Panirandawa and Wilagedara iron ore deposits and subsequently for other large deposits such as Eppawala apatite deposit and Seruwila copper magnetite deposit. These surveys were useful for outlining configurations of the mineralized zones integrated with other exploration tools but some surveys had to be abandoned later as the surface area was found to be highly disturbed due to past mining and agricultural activities. Recently, many studies have been conducted on trace element geochemistry of gem sediments to detect important indicators to locate hidden gem beds in southwestern Sri Lanka. Since 1980s, geochemical studies conducted on crustal evolution beneath Sri Lanka for characterization of isotopic signatures of tectonically juxtaposed main lithotectonic units have been remarkable enhanced. As Sri Lanka is located in a crucial position in Gondwana reconstruction, its geochemical and isotopic signatures are much valuable in correlating with other Precambrian terrains. Countrywide Geochemical mapping programme was initiated by the GSMB to establish geochemical background levels of nutrients and toxic elements in soils (Environmental Series) and to identify of possible mineralizations using both regolith and stream sediment data (Exploration Series). Future geochemical exploration surveys need to be focused on multiple perspectives such as sustainable exploitation of mineral resources, environmental monitoring and crustal studies using advances in geochemical exploration technology.

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