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# A multi-element baseline geochemical database from the western extension of the Central Africa Copperbelt in north-western Zambia

R. M. Key, B. De Waele and A. K. Liyungu

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*A stream sediment geochemical survey was undertaken in the extreme north-west of Zambia with three primary objectives: (i) to provide a baseline environmental database for an area uncontaminated by heavy industry, mining and intensive farming; (ii) to detect metal anomalies that may indicate potentially economic mineral deposits; and (iii) to provide a tightly controlled geochemical database that can be used as a standard for future mineral exploration programmes throughout central Africa. Three major geological domains underlie the studied area. These are crystalline Neoproterozoic to Palaeoproterozoic basement, an overlying sequence of Neoproterozoic Katanga strata within the western part of the Lufilian Arc (a Pan African orogenic belt that hosts major copper–cobalt deposits in the Central African Copperbelt of northern Zambia and the Democratic Republic of Congo [DRC]), and extensive Caenozoic Kalahari Group sediments. Stream sediments collected from each of the three geological domains have distinctive geochemical signatures. Relatively high values for a range of elements including uranium, thorium and yttrium were found in stream sediments within the pre-Katanga basement domain. Enhanced values of a larger number of elements are present in the stream sediments underlain by Katanga strata including significant, previously unknown, copper anomalies that warrant detailed follow-up work.*

*The high metal values in sediments derived from Katanga strata contrasts sharply with sediment samples collected from drainage channels in areas of thick Kalahari sand, which mostly have very low values of all analysed elements. Our results suggest that it will be difficult to detect contamination of streams in the Copperbelt areas of Zambia and the Democratic Republic of Congo due to their naturally high metal concentrations. By contrast, it will be relatively easy to monitor pollution of areas underlain by Kalahari sands as these have naturally very low values of all elements.*

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## INTRODUCTION

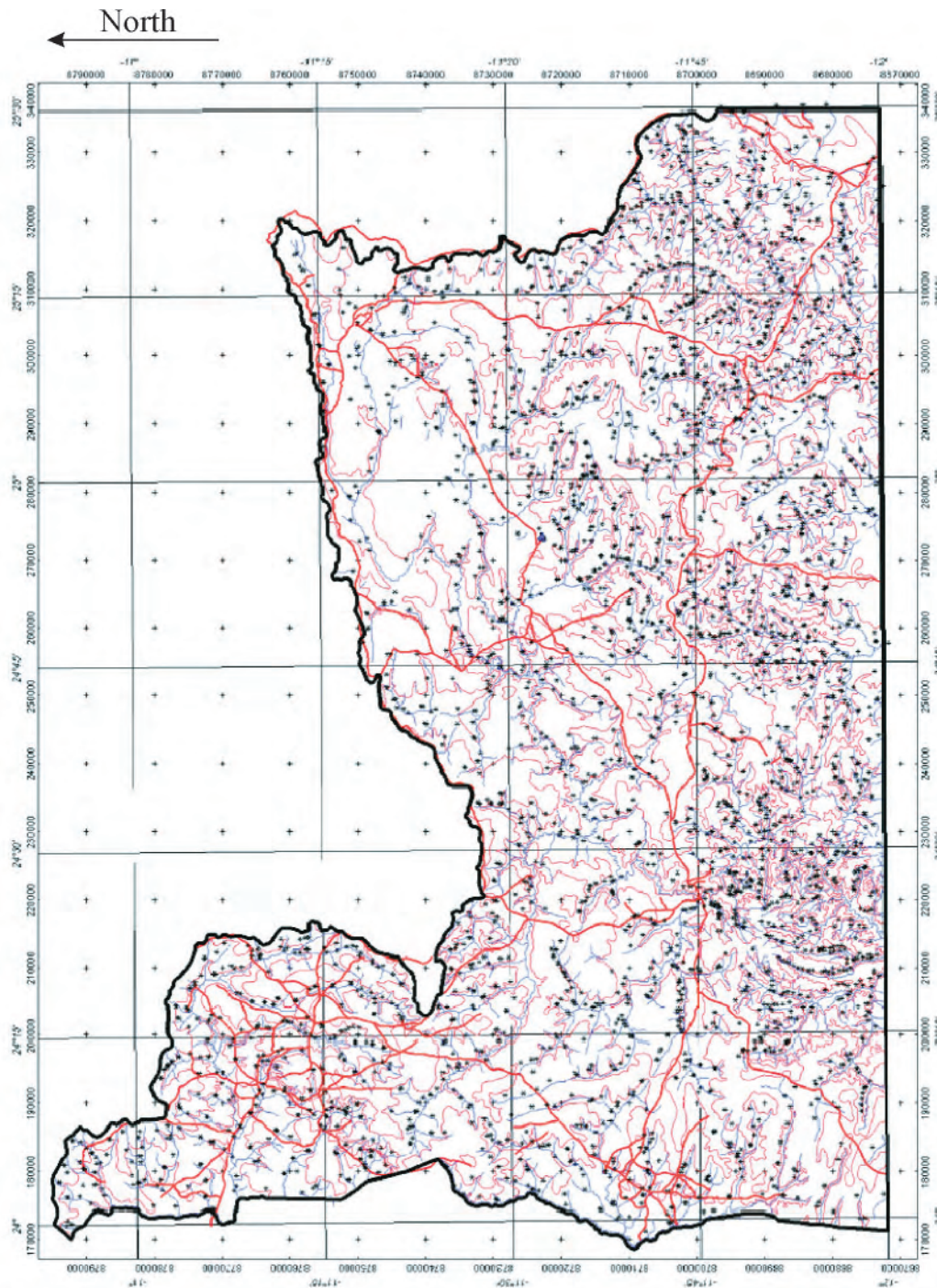
A stream sediment survey was undertaken of an area of about 13 500 km<sup>2</sup> in the extreme north-west of Zambia (to cover the 1:250 000 Mwinilunga Sheet, SC-35-13; Fig. 1) between 1998 and 2000 as part of a World Bank-funded geological mapping project by BGS and the Zambian Geological Survey. The stream sediment survey had three primary objectives: (i) to provide a baseline geochemical database that can be used to monitor pollution due to mining and agriculture in the region; (ii) as an exploration tool for uranium, base and precious metals; and (iii) to provide a tightly controlled multi-element geochemical data base that can be used as a standard for future geochemical exploration elsewhere in central Africa.

The extreme north-western part of Zambia is an unspoilt rural area with no history of mining or of modern intensive agriculture. It is sparsely populated and local people have maintained a traditional lifestyle with small fruit and vegetable gardens and small stocks of animals. A well-developed drainage

network forms the headwaters of the upper Zambezi River and provides an abundant supply of clean water for the local people. Collected stream sediments are, therefore, uncontaminated.

Three major geological domains underlie the studied area. These are a crystalline Neoproterozoic to Palaeoproterozoic basement, overlying Neoproterozoic Katanga strata within the western part of the Lufilian Arc orogen and extensive Caenozoic Kalahari Group sediments. A total of 3024 stream sediment samples were collected and analysed by ICP-MS for 40 elements. The samples were also analysed for gold, platinum and palladium by Fire Assay, and for uranium by XRF. Samples were wet sieved in the field and the <math>-100\mu\text{m}</math> fraction was bagged for analysis.

The geology of the mapped area is described in a series of Zambian Geological Survey reports<sup>21,22,24,28,29</sup> that accompany geological maps of the five component 1:100 000 sheets. An overview of the geology is given in a memoir<sup>25</sup> of the Zambian Geological Survey and is also summarised in Key *et al.*<sup>26</sup>



**1** The study area and the location of the collected stream sediment samples (black dots). Motorable tracks are in red. Crosses are spaced at 10 km intervals. The slight offset of the sample points from the drainage channels is due to scale of the figure

**Fieldwork, data capture and processing**

A total of twenty-one 1:50 000 sheets were geologically mapped and sampled. As many as five separate field teams were operating independently at any given time from base camps established within each map sheet. Field observations and sample locations were plotted (using hand-held GPSs) onto 1:50 000 topographical maps. Stream sediment samples were collected at an average density of one sample every 4.5 km<sup>2</sup>. A satisfactory aerial distribution of collected samples was achieved (Fig. 1), as there is a well-developed drainage

network over most of the Mwinilunga Sheet. Information on the mineral composition of every collected stream sediment sample, the nature of the stream at the sample locality and on any exposed bedrock was recorded on specially designed field forms. The completed forms are all archived at the Zambian Geological Survey Department. All the data recorded on these forms were later digitally recorded and stored on CDs, also at the Zambian Geological Survey Department. The collected stream sediment samples were analysed for 42 elements at the XRAL laboratories

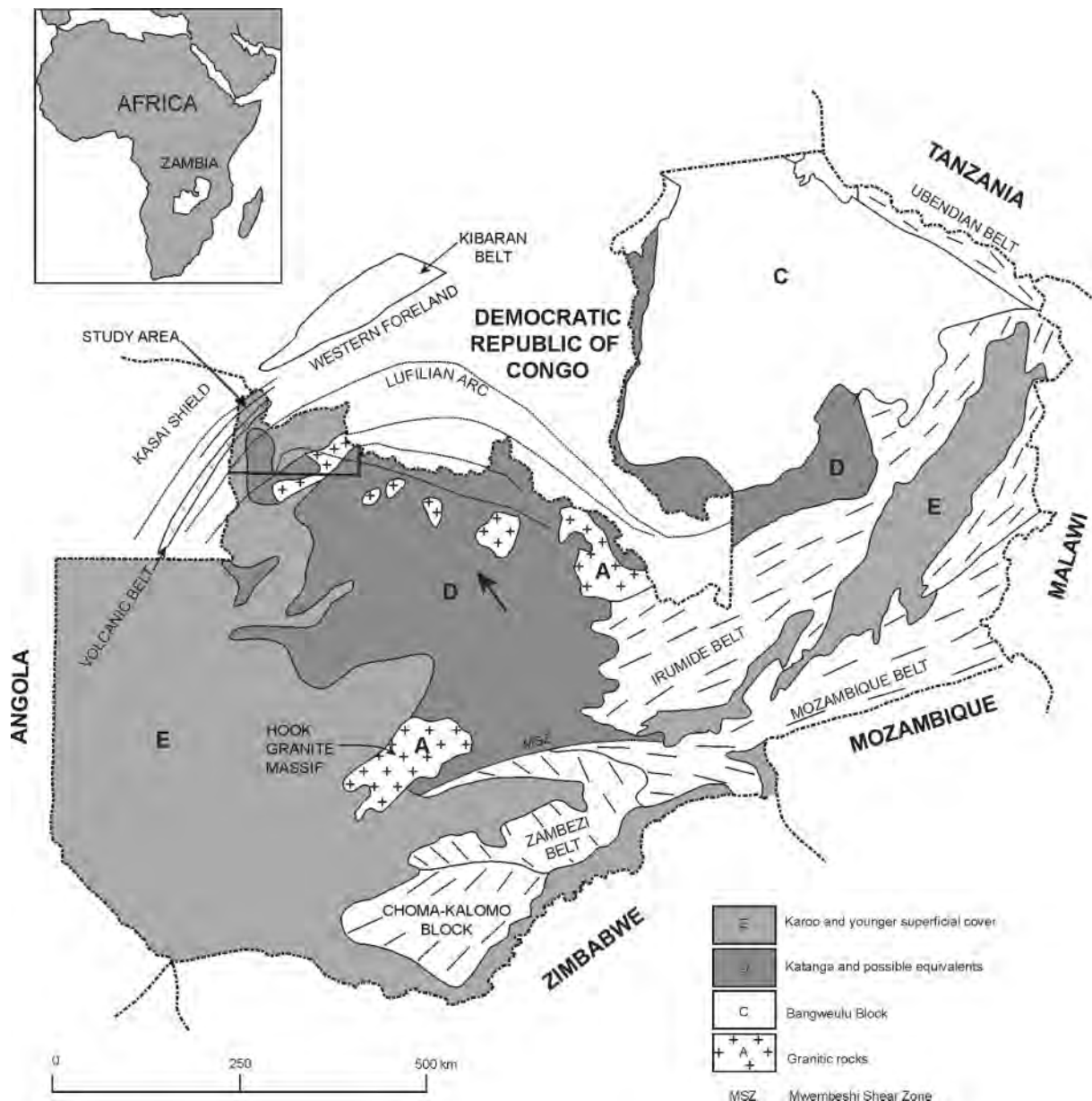
in Canada who provided the analytical data in both hard copy and digital format. All of the analytical data were later manipulated using GEOSOFT OASIS MONTAJ 4.3 software with a CHIMERA extension at the Computo-Geological Advisory Unit of the Geology Department (University of Zambia), in order to produce statistical data on the analyses and to generate maps showing the aerial distribution of each element. A4 plots showing the gross distribution of each of the 42 analysed elements are shown in Key *et al.*<sup>25</sup> In addition, 1:250 000 colour maps were produced to show in detail the aerial distribution of each of the 26 elements that showed significant regional variations in their values. Hard copies of these maps are archived at the Zambian Geological Survey Department. The processed digital data, on CDs, is also archived at the Zambian Geological Survey Department.

**Regional geological setting**

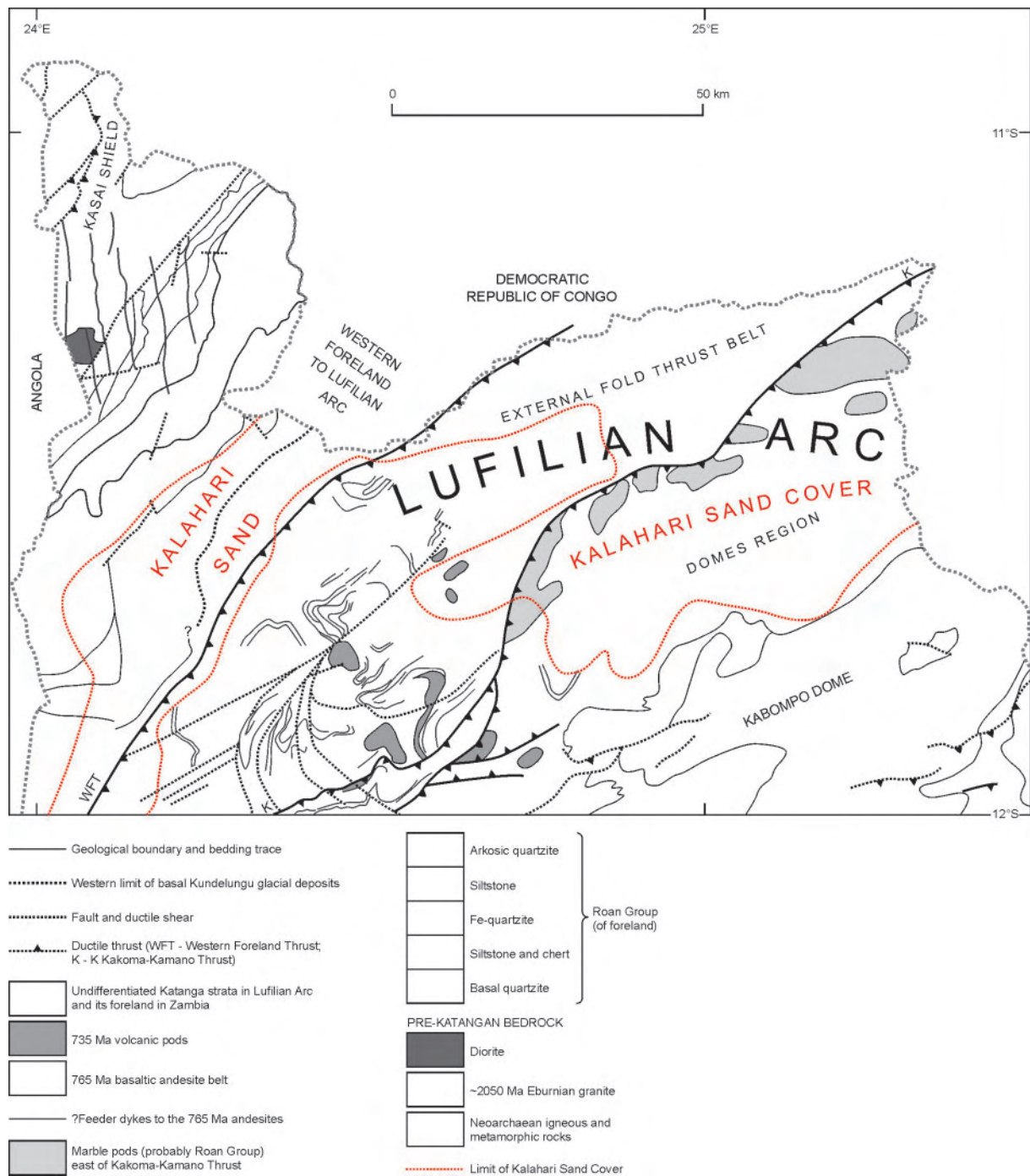
Figure 2 summarises the geology of Zambia and shows the location of the Mwinilunga Sheet. The

dominant geological feature of the Mwinilunga area is the Pan African Lufilian Arc or Lufilian Fold Belt (originally referred to by Garlick in Mendelsohn<sup>30</sup> as the Lufilian Orogeny) that has a NE–SW trend across the Mwinilunga Sheet. In the southern part of the DRC, the fold belt sweeps eastwards and then south-eastwards to re-enter northern Zambia in the vicinity of its Copperbelt.<sup>33</sup> The following lithostratigraphy (at Group level) is adopted for the Katanga rocks of the Lufilian Arc:<sup>7,10,36,49</sup> Upper Kundelungu Group; Lower Kundelungu Group (with basal glacial rocks); Mwashia Group; Upper Roan Group; and Lower Roan Group (basal unit).

The north-western extremity of the Mwinilunga Sheet lies to the north-west of the Lufilian Arc and forms part of the Kasai Shield (or Congo Craton). There are weakly deformed Katanga strata immediately west of the Lufilian Arc that unconformably overlie crystalline rocks of the Kasai Shield. Extensive Cenozoic Kalahari Group sediments that mantle most of Western Zambia encroach into the Mwinilunga Sheet



**2 The regional tectonic setting of the study area**



### 3 A simplified geological map of the study area

where they comprise continental sediments laid down on a flat Miocene Surface.<sup>34</sup>

#### Summary of the geology

Table 1 summarises the geology of the study area (Fig. 3). The Kasai Shield consists of Neoarchaean migmatites intruded by large Neoarchaean to Palaeoproterozoic equigranular and porphyritic granite and minor leucogranite and doleritic to dioritic stocks and dykes. Palaeoproterozoic (Ubendian) granitic and migmatitic rocks and associated schists form the core of the Kabompo Dome in the south-eastern part of the area within the Domes Region of the Lufilian Arc.<sup>27,32,38,42,43</sup> Katanga strata underlie the greater part of the Sheet.

They form a gently deformed sequence (up to and including the basal Kundelungu glacial deposits) in the north-west of mostly platform sediments with a major volcanic unit within a Western Foreland to the Lufilian Arc. Katanga strata in the Lufilian Arc are strongly deformed and it is generally not possible to unravel original stratigraphical relationships, especially within the outer Fold-Thrust Belt of the Lufilian Arc. However, in the extreme south-east within the Domes Region of the Lufilian Arc, basal Katanga strata form a carapace over the Kabompo Dome. Here, it is possible to correlate the basal Katanga rocks with Roan Group units identified elsewhere in NW Zambia.<sup>31</sup> Small mafic to intermediate stocks and dykes intrude the Katanga

**Table 1** A summary of the geological history of the Mwinilunga Sheet (modified from Key *et al.*<sup>26</sup>)

Age	Geology
Caenozoic	Quaternary river systems eroding and redepositing sediment. E–W and N–S warping controls the rivers systems Kalahari Group sediments deposited subaerially on a Miocene land surface
Not Dated	Long period of erosion with formation of residual soils
End-Precambrian to early Palaeozoic (~645–513 Ma) Pan African	Tectonothermal events that produced a fold/thrust pile within the Lufilian Arc with associated Amphibolite to Greenschist Facies regional metamorphism, and high-pressure metamorphism in the lower parts of ductile thrust planes. Main deformation at ~560–550 Ma. <sup>36</sup> Tectonic transport in a northerly direction of a southern plate (Kalahari Shield) impinging on the Kasai Shield (zone of contact to the south of the Mwinilunga Sheet). The Lufilian Arc comprises an outer Fold-Thrust Belt domain and an inner Domes Region domain <sup>36</sup> in the Mwinilunga Sheet
~735 Ma	Calc-alkaline volcanic centres within Kundelungu siliciclastic and glacial sediments, carbonates and ironstones
~748 Ma	Glaciomarine deposits that mark the start of Kundelungu sedimentation
~765 Ma	Calc-alkaline volcanism in rift setting along the western margin of the Katanga (Mwashia Group) sedimentary depository. Possible emplacement of minor subvolcanic intrusions and N-trending mafic dykes. Unrug <sup>42,43</sup> traced the volcanics into Angola. Weathering of the volcanics resulted in deposition of volcanoclastic sediments
~880 Ma	Start of Roan Group sedimentation on a continental shelf underlain by Kasai Shield crystalline rocks. Siliciclastic sediments with laterally discontinuous limestones
Not dated	Emplacement of NE-trending mafic dykes and dolerite sheets and NE-trending ductile, sinistral shearing as well as thrusting with tectonic transport in several directions, but mainly to the NW
~1940–1850 Ma	Emplacement of major porphyritic granite intrusions (Domes domain)
~2050 Ma Ubendian	Emplacement of major porphyritic granite intrusions as well as leucogranite dykes (Kasai Shield)
~2560 Ma	Major tectonothermal event with generation of migmatites and associated granitic magmatism (Congo Craton). Possible emplacement of dioritic stocks

strata. These have been metamorphosed with the surrounding Katanga rocks to suggest that they are either contemporaneous with the extrusive Katanga volcanics or only slightly younger.

Following deposition, the Katanga sediments were subjected to a major period of thrusting and associated folding within the Pan African Lufilian Arc. In the east (within the Domes Region) the folds trended E–W to NE–SW and were essentially upright. Associated thrusts verged towards the north-west. In the west (External Fold-Thrust Belt) the early folds formed large recumbent nappes and associated thrusts verged towards the north-east. Open folds later refolded the early folds and associated thrusts (and shears) with N–S to NW–SE trending axial traces. At a later stage, possibly associated with uplift and erosion, the rocks were fractured with prominent NE- and NW-trending faults. Associated with the early folding and thrusting was a regional metamorphism that increased from Amphibolite Facies in the lower Katanga strata east of the Kakoma-Kamano Thrust to Greenschist Facies west of this thrust. High-pressure mineral assemblages, including talc-kyanite-schists,<sup>12,44</sup> formed in the lower parts of ductile thrust sheets. Locally the thrusting has interleaved high-grade rocks into lower grade rocks, as seen along the southern margin of the Mwinilunga Sheet. The later folding was associated with Greenschist Facies metamorphism that locally retrogressed earlier metamorphic mineral assemblages.

Continental sediments of the Kalahari Group include aeolian sands and associated silcrete and ferricrete were laid down over residual soils on a

peneplained Miocene land surface.<sup>33</sup> Later warping on E–W axes of this land surface with its sand cover controls the present drainage pattern. In the north-east, there is on-going faulting parallel to the warping.

### Drainage

The studied area forms the headwater catchment of the Zambezi River System with the watershed between this river system and the Congo River system defining the area's northern limit as the political border between Zambia and the Democratic Republic of Congo (DRC). The source of the Zambezi River is located north of Mwinilunga where the river flows northwards and then westwards across the grain of the bedrock. The Zambezi River has a dendritic network of tributaries with several major tributaries, including the Sakeji, Kasanjiku, Kabompo and Mwinilunga rivers. However, the north-eastern area is poorly drained with individual drainage channels controlled by active faulting. As a result of the faulting, rivers that previously flowed northwards as part of the Congo River System now flow west and southwards into the Mwinilunga River. By contrast, the Congo River System is dominant in the north-western part of the area where it is capturing right-bank tributaries of the Zambezi River upstream of its confluence with the Sakeji River. The majority of watercourses are perennial and only the very small, low order tributaries of the southern rivers dry up during the dry (winter) season. However, flow rates are variable with extensive dambos (seasonally saturated, channel-less valley floors) developed in the slowly flowing north-eastern rivers.

### Local conditions relevant to the stream sediment geochemistry

The Mwinilunga Sheet is an unspoiled rural area with self-sufficient local communities growing their own food in small-holdings around their villages and keeping small stocks of goats, pigs and sheep. Large herds of cattle are only kept on several large farms, and one farm is developing coffee production on a commercial scale. Aid agencies and NGOs have tried to encourage fish farms by diverting and ponding the courses of rivers. However, fishing is still mainly done by traditional methods using fish weirs, fish traps and lines. Therefore, no contamination by the local communities of the stream sediments is likely.

Mwinilunga Town is the only large settlement in the study area, which is otherwise extremely sparsely populated. (The total population of the whole of the NW Province including the provincial capital, Solwezi, was only 545 150 in 1990.) Therefore contamination of stream sediments associated with waste disposal from large human communities is unlikely. Similarly, contamination associated with large volumes of traffic is not an issue. There are few cars in the area and the only tarred road links Mwinilunga with Solwezi to the east and continues to the Copperbelt towns. There are also widely separated motorable gravel roads from Mwinilunga towards the major villages and between these villages. Due to the very poor network of tracks in the north-eastern area, many of the local people travel by canoes along the West Lunga and Nwila rivers.

There is, and never has been any major mining. Small roadstone and building stone quarries as well as burrow pits (mainly in laterite) are found along the motorable tracks and main road. Several small copper showings have been examined with shallow trenches and some minor underground workings. This work has been confined to the immediate areas of surface showings and has not contaminated the drainage network.

### Climate, soils and vegetation

The climate is typically tropical (classed as Tropical Savannah) with hot wet summers lasting from October or November until April, and intervening dry warm winters. The annual rainfall exceeds several hundred centimetres with major storms a feature of the wet summer season. The stream sediment sampling programme took place during the dry season.

Ting-tiang<sup>40</sup> showed a variety of acidic soils covering the whole of the Mwinilunga Sheet. These include various acrisols, arenosols and gleysols in areas underlain by Kalahari sands and related sediments (see below). Ferralsols were shown in the southern part of the Mwinilunga Sheet and clayey soils in the north-west. The BGS-Zambian Geological Survey Department Project team mapped five categories of superficial deposits:

- \* *Recent white sands and contemporaneous silcrete formation*
- \* *Alluvial deposits including floodplain silts, pan and dambo sediments*
- \* *Kalahari Group sandy soils and thick sands with associated silcrete and ferricrete beds*

\* *Residual clayey loams underlying large expanses of grassland with perched shallow aquifers*

\* *Residual loamy, lateritic and clayey soils.*

The present drainage systems are stripping away the unconsolidated Kalahari sediments to expose underlying residual soils and in extreme cases the underlying bedrock. This process is most advanced in the major river valleys in the southern part of the Sheet. Clayey soils are exposed in the far north<sup>40</sup> where north-bank tributaries of the Zambezi River are stripping away the Kalahari Group sediments to reveal large granite pavements with thin overlying soils. The various Kalahari Group sediments are preserved along interfluvies, especially in the northern half of the sheet. A basal silcrete layer locally forms a ridge feature that is better developed to the south of the sheet.<sup>16</sup>

Alluvial deposits in the active streams and rivers are dominated by white to pale brown sands derived from eroded Kalahari Group sediments. The various floodplain, pan and dambo sediments are darker with dominant silt and clay fractions. Recent clean white sands form thin veneers on the margins of active rivers and along the margins of the floodplains. They are regarded as the residues of flash flood sediments (overbank sediments). Silcretes are forming above active faults in the north-eastern part of the Sheet.

Termite mounds (termitaria) are a major feature of the Mwinilunga Sheet. There are several morphological types that include pinnacle-forming mounds up to several metres tall in woodlands. Colonies of low (up to 1 m tall) mounds are commonly found in the grasslands. The termitaria are so abundant that they must be a major factor in controlling both the vertical distribution of minerals as well as the texture of superficial deposits. They control the conversion of Kalahari sands into sandy soils by introducing underlying residual soils into the Kalahari sands.

Edmonds<sup>15</sup> provided a 1:500 000 vegetation map of Zambia that covers the whole of the Mwinilunga Sheet. Indigenous woodland cover is now best preserved in protected forest areas. Outside of these protected areas, the woodland is being systematically cleared for agricultural land. According to Edmonds,<sup>15</sup> the commonest types of woodland are Miombo and Kalahari Woodland and Kalahari Chipya, Parinari Forest and Copperbelt Chipya. Strips of riparian closed forests flank the various watercourses. Vast expanses of grassland are devoid of trees and only locally have a scrub cover (of *Oapaca kirkiana*).

### Mineral exploration

Modern prospecting in Zambia (or Northern Rhodesia as it was then called) commenced in about 1885 according to De Swardt and Drysdall.<sup>14</sup> In 1922, the British South Africa Company, who held the mineral rights to the country, started releasing large concession areas for mineral exploration to large mining and financial institutions. This led to a major period of mineral exploration between 1923 and 1940 that included coverage of the whole of the

Mwinilunga Sheet by the Rhodesia Congo Border Concession Ltd (Rhokana Concession Ltd). Brock<sup>9</sup> and Guernsey<sup>17</sup> documented this work, and a later account of the geology of Northern Rhodesia by Guernsey<sup>18</sup> is essentially based on these two reports. New Consolidated Goldfields and RST undertook detailed exploration work, including airborne scintillometer surveys in the late 1950s and early 1960s that was mainly confined to the southern half of the Mwinilunga Sheet. New metal anomalies were discovered although follow-up work with a limited amount of diamond drilling failed to locate any economic mineralisation.<sup>45</sup> Tika<sup>39</sup> reported on a widespread search for iron deposits in NW Zambia that encompassed the eastern part of the Mwinilunga Sheet. Anglo American held large mineral concession areas around Mwinilunga in the mid 1990s and undertook stream sediment, rock and soil geochemistry as well as ground and airborne geophysical surveys. This work was curtailed without finding any new significant base or precious metal mineralisation.<sup>5</sup> There is on-going exploration for metals by a number of companies.

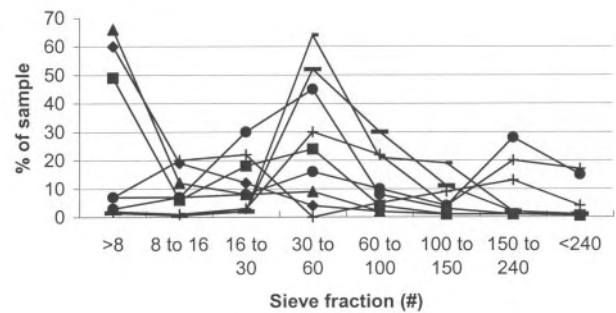
Agip<sup>1-4</sup> commenced a pioneering exploration programme for uranium in the early 1980s. This included airborne spectrometer surveys and led to the discovery of several anomalies in the south-eastern part of the Mwinilunga Sheet. Follow-up groundwork failed to find significant mineralisation. Prospectors in search of gemstones have wandered across the area leaving behind a number of shallow pits and trenches without finding any mineral deposit of worth.

### STREAM SEDIMENT GEOCHEMISTRY

Two orientation surveys<sup>20,23</sup> were undertaken at the start of the field campaign in order to establish the optimum sampling procedures in the field, and the best sample preparation and chemical analytical techniques to meet the three principal objectives of the whole programme.

In the first orientation survey, nine bulk stream sediment samples were collected from streams draining areas underlain by the main bedrock units and from streams underlain by Kalahari Group sediments. A stream draining the only known copper prospect (Luamata) was also sampled; one sample immediately downstream of the exposed copper-bearing strata and a second sample from 1 km further downstream. Different stream sizes and types were sampled ranging from a fast-flowing major tributary (Sakeji River) of the Zambezi River to a dry, low-order small tributary of the Mwinilunga River. Silt from a stagnant dambo and sand-dominated sediment from an adjacent flowing stream were also collected to compare their geochemical signatures.

The samples were sieved in the field and each size fraction was chemically analysed (after crushing) to establish which sieve fraction would be collected during the main sampling programme for chemical analysis. Previous stream sediment sampling programmes<sup>5,6,11,19,37,41,46-48</sup> undertaken by exploration



### 4 Sieve fraction analysis of 9 bulk stream sediment samples

companies and government agencies for mineral exploration used either the  $< 180 \mu\text{m}$  or  $< 75 \mu\text{m}$  sieve fractions. By comparison, following an international review, Darnley *et al.*<sup>13</sup> recommended that  $< 150 \mu\text{m}$  size fractions should be used for regional stream sediment geochemical programmes. The same fraction was also recommended by Plant.<sup>35</sup>

The results of the first orientation survey indicated that the grain size of the analysed sediment is not critical (Table 4), although the finer fractions do show enhanced values for most elements (except Cr, Fe, Co and As). In order to conform to the recommendation of Darnley *et al.*,<sup>13</sup> it was decided that the  $< 150 \mu\text{m}$  fraction would be collected and analysed during the main sampling programme. The sieve analyses (Fig. 4) of the nine bulk samples showed that there would be sufficient material in sediments from all river types (including sediments dominated by sand and gravel) to enable the sampling parties to collect enough material for chemical analysis quickly. A sample collection form was designed (Fig. 5) for completing in the field. The data recorded on these forms provide a complete description of the stream, the nature of the collected sample and of the underlying geology at the collection point.

A petrographical study of the collected sediments showed that all, except the finest and coarsest fractions, are dominated by rounded, clear to brown-stained quartz grains with only minor amounts of other minerals (including various micas and locally garnet), lithic fragments and opaques. In the coarsest fractions, there is a higher proportion of lithic clasts and the quartz grains are less rounded. The stream sediment collected immediately downstream of the copper prospect was found to be enriched in all metals, not just copper, and enhanced (albeit lower) values were also found in the sample that was collected 1 km downstream of the prospect. There are differences between the chemistry of the sampled dambo silts and sands from an adjacent active stream. The silts are enriched in Li, Be, Na, P, Ti, Y, Nb, Mo, Sn, Ba, La, Nd and Yb but depleted in Ca, Cr, As, Eu and Ta. As a result, it was decided to collect samples only from active channels during the main survey and samples were collected from the narrow parts of dambos where there was flowing water.

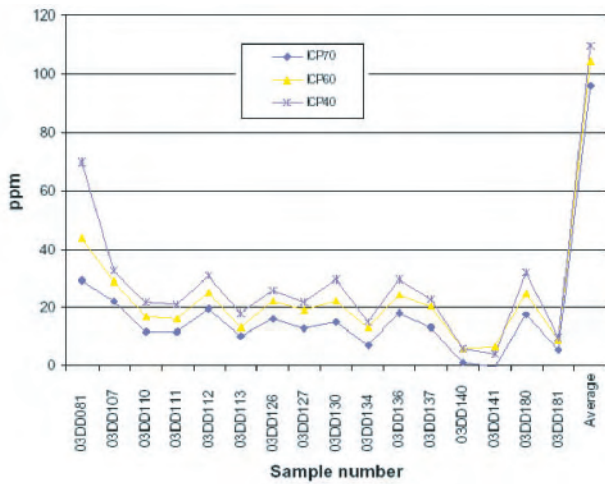
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SAMPLE NUMBER:		<input type="text"/>	<input type="text"/>	<input type="text"/>
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GPS reading:	S		E	
Full UTM co-ordinates :				
Elevation (metres):				
Stream name or unnamed tributary to named stream:				
<i>Tick one of the following boxes in each category</i>				
Stream width:	1 metre <input type="checkbox"/>	1 - 5 metres <input type="checkbox"/>	5 - 10 metres <input type="checkbox"/>	10 metres <input type="checkbox"/>
Nature of stream:	Flowing water <input type="checkbox"/>	Stagnant water <input type="checkbox"/>	Dry <input type="checkbox"/>	
Bank height:	1 metre <input type="checkbox"/>	1 - 5 metres <input type="checkbox"/>	5 - 10 metres <input type="checkbox"/>	10 metres <input type="checkbox"/>
Exposed rock at, or immediately upstream of sampling locality:	Yes <input type="checkbox"/>	No <input type="checkbox"/>		
Exposed rock code:	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Signs of contamination at sample locality:	Yes <input type="checkbox"/>	No <input type="checkbox"/>		
Type of contamination:	Industrial <input type="checkbox"/>	Agricultural <input type="checkbox"/>	Domestic <input type="checkbox"/>	Construction <input type="checkbox"/>
Obvious heavy mineral trail:	Yes <input type="checkbox"/>	No <input type="checkbox"/>		
Organic matter in stream sediment:	Yes <input type="checkbox"/>	No <input type="checkbox"/>		
Dominant stream sediment:	Gravel <input type="checkbox"/>	Sand <input type="checkbox"/>	Fines <input type="checkbox"/>	
Comments:				
Collector's initials:	<input type="text"/>	<input type="text"/>	<input type="text"/>	
Project Code:	<input type="text"/>	<input type="text"/>		

### 5 The sample collection form

During the first orientation survey, on the recommendation of exploration companies with first-hand experience of stream sediment geochemical programmes in NW Zambia, the collected sediments were analysed by ICP following ‘total’ digestion (by *aqua regia* mixed with a few drops of hydrofluoric acid). This laboratory procedure successfully detected chemical differences in sediments from streams underlain by different bedrock and superficial deposits and also detected significantly higher metal values in sediments from a stream draining the known copper–cobalt deposit. Nevertheless, in order to confirm that a ‘total’ digestion followed by multi-element ICP analysis was the most suitable method of

examining the stream sediments of the Mwinilunga Sheet; a second orientation survey was carried out. The < 150 µm fraction of a much larger sample batch (about 5% of the anticipated total sample population) was collected and sent for analysis. Three different digestion techniques were undertaken prior to ICP analysis on these samples. In addition, gold, platinum and palladium were analysed by Fire Assay, and an atomic absorption hydride analysis was carried out for arsenic and antimony.

As a quality control on the analytical laboratory, a number of duplicate samples were also sent to two other laboratories. The following digestion and analytical techniques were applied to the collected samples:



## 6 A comparison of copper analyses using the three different analytical techniques tested during the second orientation survey

- *ICP40* – a ‘total’ digestion solvent of aqua regia with a few drops of hydrofluoric acid, followed by ICP analysis of 40 elements (as used in the first orientation survey)
- *ICP60* – a digestion solvent of hydrochloric acid followed by ICP analysis of 31 elements
- *ICP70* – a digestion solvent of aqua regia followed by ICP analysis of 31 elements
- *FA301* – fire assay for gold, platinum and palladium (also carried out in the first orientation survey)
- *AAH70* – atomic absorption hydride analysis for arsenic and antimony.

The analytical results for the three different ICP methods indicated that the ICP40 ‘total’ digestion and analytical method should be used on samples collected during the main stream sediment sampling programme for the following reasons:

- The ICP40 package gives better analytical resolution for almost all elements, with the widest range of values. Thus, the higher values given by ICP40 for most elements provide a greater spread of results with better resolution of the highest values as well as the lowest values close to the detection limit (Fig. 6).*
- The reproducibility (accuracy) of the ICP40 results is consistently excellent whereas some of the ICP60 and ICP70 duplicate results were poor.*
- Arsenic was detected by the ICP40 method in samples found to contain high arsenic values by the AAH70 method. This would indicate that the ICP40 method should detect any major arsenic values during the main stream sediment-sampling programme to make it unnecessary to also use the AAH70 method.*
- More elements are analysed (40 against 31) by ICP40. Three elements (Zr, W and Sb) not analysed by ICP40 were mostly present in too small amounts to be detected by ICP60 and ICP70.*

In contrast to the first orientation survey where the various size fractions (except the very finest) were

crushed prior to analysis, the second orientation survey (< 150 µm) samples were not crushed prior to any of the chemical analyses. During the first orientation survey, crushing of the samples introduced gold contamination. Excellent similarities between the analyses of all elements from the three different laboratories (Fig. 7) indicate that the XRAL analyses are of a high standard, and this laboratory was used to analyse all the samples collected during the main survey.

### The main stream sediment sampling programme

It was anticipated in the planning stages of the stream sediment sampling programme that 2981 samples would be collected at a mean density of about one sample every 4.5 km<sup>2</sup>. Anticipated sample collection points were marked on all the 1:50 000 topographical sheets within the Mwinilunga Sheet. The sampling programme was based on its total budget, the distribution of streams and the manpower and time constraints. The main sampling programme took place during the second half of 1998 and the first half of 1999. Sieving of the stream sediments generally took place at the collection points as most streams contained flowing water. The < 150 µm fraction was collected in Kraftcc bags and a portion of the generally more abundant > 150 µm fraction was also collected. Sample batches comprising one Kraftcc bag containing about 100 g of the < 150 µm sample from each collecting point were sent to XRAL in Toronto for chemical analysis. The remaining stream sediment material was stored at the Geological Survey Department in Lusaka.

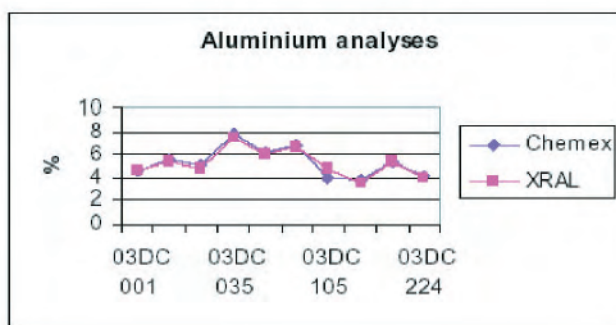
The samples sent to Toronto were analysed for 40 elements by ICP; fire assays were undertaken for gold, platinum and palladium, and XRF was used to determine uranium. The AAH analyses for arsenic and antimony tested in the second orientation survey were abandoned, as the ICP40 method detects arsenic, and antimony was generally present in too low concentrations to be detected by AAH. It was decided to analyse for uranium by XRF due to: (i) the low detection limit (2 ppm) of this method relative to ICP40; (ii) the potential for uranium mineralisation,<sup>30</sup> as known occurrence of uranium mineralisation occurs in the south-eastern part of the Mwinilunga Sheet; and (iii) the budget was sufficient for this additional set of analyses.

### The geological classification of the collected stream sediment samples

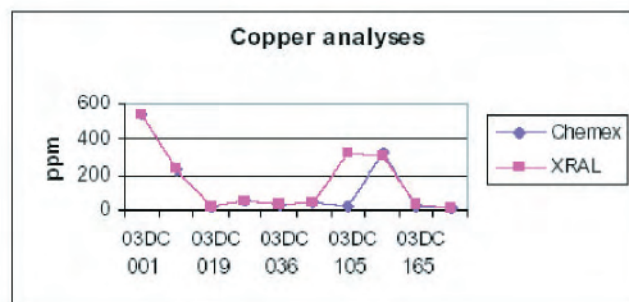
The stream sediment samples were geologically coded according to which of the following three lithological groups underlies the collection point.

- Pre-Katanga Basement** – collection points where the pre-Katanga rocks are exposed, or covered by less than ~2 m of residual soils.
- Katanga strata** – collection points in hilly or rugged areas where Quaternary weathering is stripping away residual soils and Kalahari Group sediments so that Katanga strata are either exposed or covered by less than ~2 m of superficial sediments.

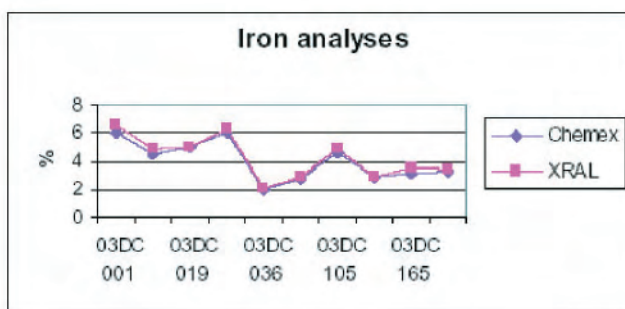
Al%	Chemex	XRAL
03DC 001	4.57	4.53
03DC 007	5.55	5.38
03DC 019	5.14	4.81
03DC 035	7.73	7.42
03DC 036	6.22	6.04
03DC 093	6.87	6.63
03DC 105	3.96	4.79
03DC 152	3.8	3.45
03DC 165	5.43	5.36
03DC 224	4.19	3.96



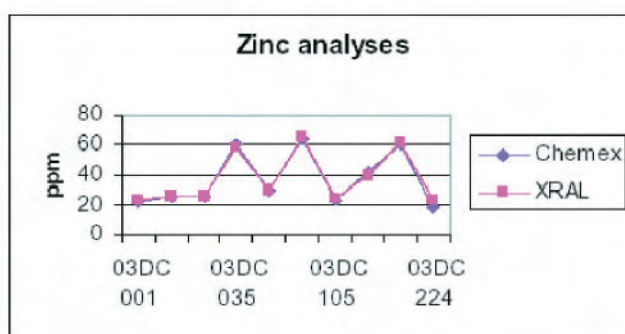
Cu (ppm)	Chemex	XRAL
03DC 001	537	536
03DC 007	232	231
03DC 019	23	21
03DC 035	50	51
03DC 036	26	28
03DC 093	37	38
03DC 105	22	325
03DC 152	318	295
03DC 165	24	26
03DC 224	8	10



Fe%	Chemex	XRAL
03DC 001	5.98	6.6
03DC 007	4.43	4.8
03DC 019	4.99	5.04
03DC 035	6.08	6.35
03DC 036	1.92	2.07
03DC 093	2.75	2.94
03DC 105	4.64	4.79
03DC 152	2.86	2.9
03DC 165	3.18	3.54
03DC 224	3.3	3.44



Zn (ppm)	Chemex	XRAL
03DC 001	22	23
03DC 007	26	26
03DC 019	26	26
03DC 035	60	58
03DC 036	30	29
03DC 093	64	65
03DC 105	24	25
03DC 152	42	40
03DC 165	60	62
03DC 224	18	24



## 7 Comparisons of analyses by two different laboratories

(iii) *Caenozoic deposits* – collection points where the superficial material (mostly Kalahari Group sands and silcretes) is greater than 2 m in thickness.

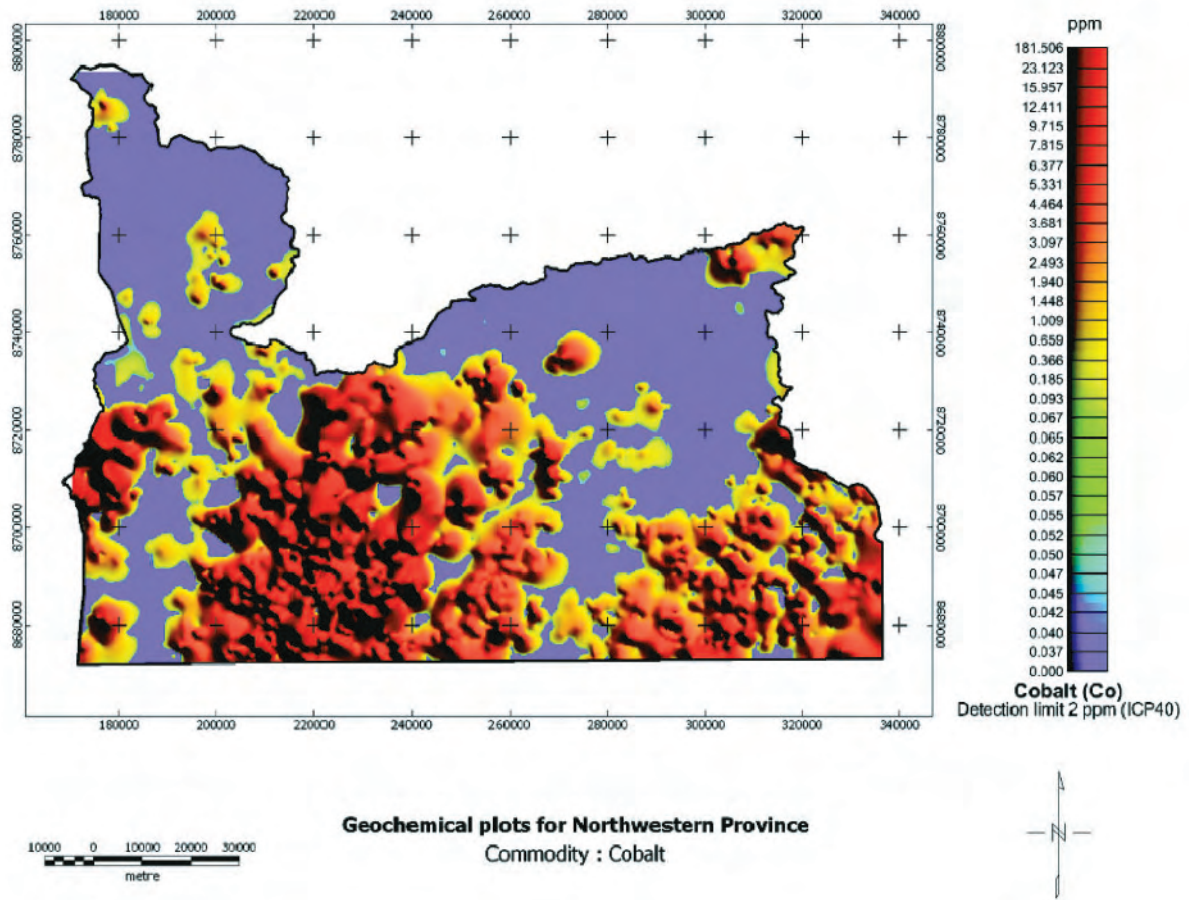
## RESULTS

A total of 3024 stream sediment samples were collected and a total of 2953 samples were analysed. Samples that were badly labelled, or that were not accompanied by completed sample collection forms were discarded. The analytical results are fully documented in Key *et al.*<sup>25</sup> as a series of maps, figures, CDs and tables.

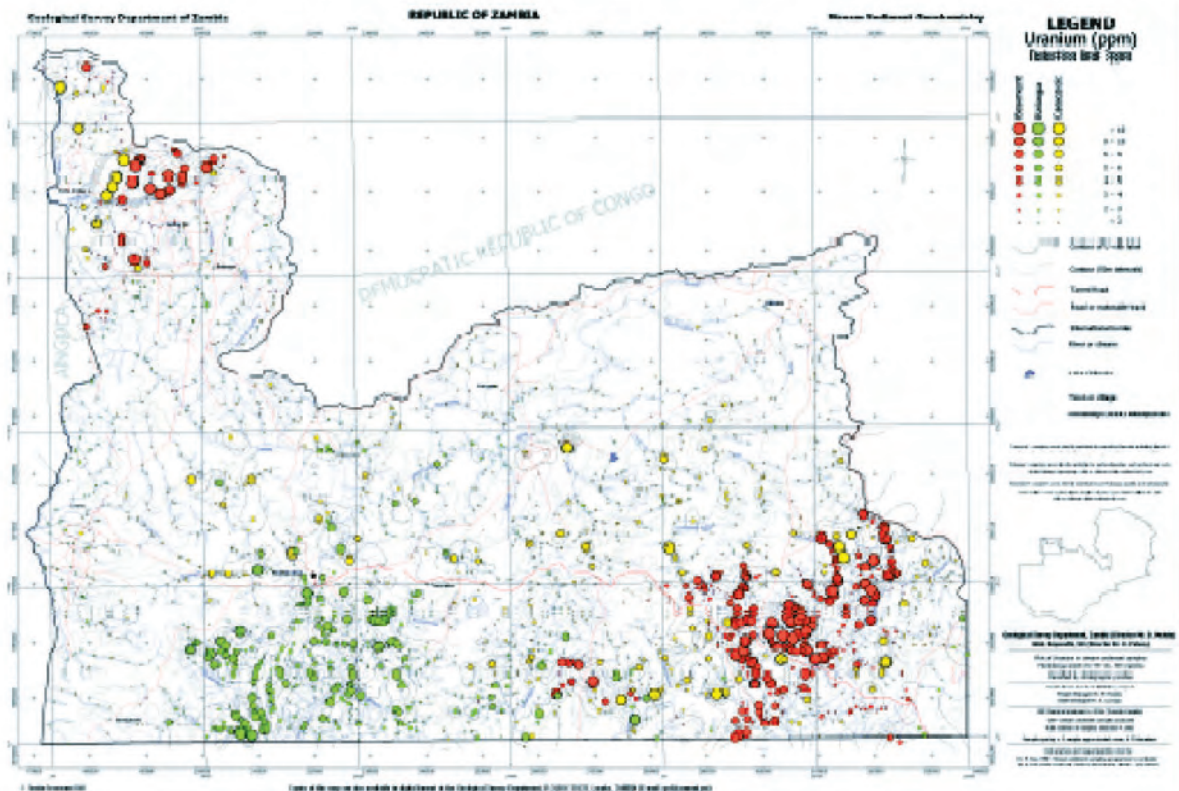
Two series of plots were produced using the GEOSOFT OASIS MONTAJ 4.3 software with a CHIMERA extension, to show the regional distribution of all the analysed elements. In producing the first series of plots, the statistical gridding method of kriging was applied. For the studied dataset of stream sediment geochemistry, it is assumed that geochemical values vary in a continuous manner from one location to the next. Therefore, points that are near each other have a certain degree of spatial correlation, but points that are widely separated are statistically independent. A semi-variogram, showing

the correlation between data points versus distance, was used to determine the nugget and slope values, and a spherical model was applied for the kriging procedure. Figure 8 shows an example of a colour-

shaded plot for the Mwinilunga sheet, depicting the regional distribution of cobalt. Such plots, provide critical information for local and central governments, and represent a 'snapshot' of the region, prior to



8 Distribution of cobalt shown by colour shading



9 Distribution of uranium shown by graduated symbols

**Table 2** A summary of chemical analyses used in the main stream sediment geochemical sampling programme

ICP40		Fire assay	
Element	Detection limit	Element	Detection limit
Gold (Au)	8 ppm	Arsenic (As)	10 ppm
Lithium (Li)*	2 ppm	Strontium (Sr)*	2 ppm
Beryllium (Be)	1 ppm	Yttrium (Y)*	2 ppm
Sodium (Na)*	0.005%	Niobium (Nb)	4 ppm
Magnesium (Mg)*	0.005%	Molybdenum (Mo)	2 ppm
Aluminium (Al)*	0.005%	Silver (Ag)	2 ppm
Phosphorus (P)*	0.005%	Cadmium (Cd)	2 ppm
Potassium (K)*	0.01%	Tin (Sn)	5 ppm
Calcium (Ca)*	0.005%	Barium (Ba)*	1 ppm
Scandium (Sc)	2 ppm	Lanthanum (La)*	2 ppm
Titanium (Ti)*	0.005%	Cerium (Ce)*	5 ppm
Vanadium (V)*	2 ppm	Neodymium (Nd)*	9 ppm
Chromium (Cr)*	2 ppm	Europium (Eu)	2 ppm
Manganese (Mn)*	4 ppm	Holmium (Ho)	4 ppm
Iron (Fe)*	0.02%	Ytterbium (Yb)	1 ppm
Cobalt (Co)*	2 ppm	Tantalum (Ta)	40 ppm
Nickel (Ni)*	3 ppm	Lead (Pb)	4 ppm
Copper (Cu)*	2 ppm	Bismuth (Bi)	10 ppm
Zinc (Zn)*	2 ppm	Thorium (Th)*	6 ppm
Gallium (Ga)	4 ppm	Uranium (U)	100 ppm

XRF	
Element	Detection limit
Uranium (U)*	2 ppm

\*1:250 000-colour plots of the distribution of these elements are available at the Zambia Geological Survey Department in Lusaka.

industrial or agricultural development. Baseline maps of this nature are essential in studies of environmental pollution as they clearly show areas of low and high element concentrations.

A second series of plots showed individual analyses as an open circle coloured to reflect the dominant underlying geology and graduated so that the larger the analytical result the larger the circle. Exploration companies can follow up isolated anomalies, as well as clusters of anomalies highlighted by this type of plot. Figure 9 shows an example of this type of plot for uranium.

The stream sediment geochemistry is summarised in Tables 2–9. These include a summary of the analytical techniques (Table 2), a statistical analysis with threshold values (Table 3), the results of chemical analyses of the different sieve fractions from the first orientation survey (Table 4), a summary of the analyses of internal standard samples (Table 5) and lists of anomalous values (Tables 6–9).

### Chemical characteristics of the three main geological groups

A summary of the analytical data for each of the three main geological groups is shown in Table 3. Relatively high values for a range of elements including uranium, thorium and yttrium were found in stream sediments within the pre-Katanga basement domain. However, it was possible to differentiate samples collected from the Kasai Shield area from those from the south-eastern basement in the Lufilian Arc. Enhanced values of a larger number of elements (not just base metals) are present in stream sediments underlain by Katanga strata. The high values in sediments derived from Katanga strata contrast strongly with sediments

collected from drainage channels in areas of thick Kalahari sand, which mostly have very low values of all analysed elements. Stream sediment samples collected from areas directly underlain by Katanga bedrock have higher values of Al, Bi, Co, Cu, Fe, Li, Mg, Mn, P, Sc, Ti, V and Zn and lower values of Pt, Al, La, Ce, Th and Y compared to samples from areas directly underlain by pre-Katanga 'basement'. Stream sediment samples from the south-eastern, pre-Katanga 'domes' area have higher values of Al, Ba, Ca, Co, Cr, Cu, Li, Ni, P, K, Na, Sr and V compared to samples from the north-western Kasai Shield. However, Th is higher in the samples from the north-western Kasai Shield (especially from the area of the mapped equigranular granite) than in samples from the Kabompo Dome. Samples from areas underlain by thick Cenozoic superficial deposits generally have lower values of all elements, although the highest copper values were recorded in samples collected from streams draining Kalahari sediments.

### Environmental database

Sediment in streams underlain by Katanga strata, and to a lesser extent by crystalline metamorphic and igneous rocks, naturally have 'high' values for a wide variety of metals and it will be difficult to detect man-made contamination of streams by analysing their sediments. However, the analytical results shown in Tables 3–9 can be used as a reference database in deciding whether there is any contamination of river systems in the Copperbelt region of Zambia and the Democratic Republic of Congo.

By contrast, the stream systems in the areas underlain by thick Kalahari Group sediments have

**Table 3** A summary of the analytical data with samples subdivided based bedrock geology

Element	Ag	Al	As	Au	Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cu	Eu	Fe	Ga	Ho	K	La	Li	Mg
Method	ICP40	ICP40	ICP40	FA	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40	ICP40
Detection limit	2ppm	0.005%	10ppm	1ppb	8ppm	1ppm	1ppm	10ppm	0.005%	2ppm	5ppm	2ppm	2ppm	2ppm	2ppm	0.02%	4ppm	4ppm	0.01%	2ppm	2ppm	0.005%
All data																						
1st quartile	0	0.380	0	2	0	20	0	0	0.010	0	13	0	9	3	0	0.2	0	0	0.05	5	0	0.010
3rd quartile	0	3.045	0	6	0	292	1	0	0.179	0	78	6	71	13	0	1.57	8	0	0.98	34	10	0.158
Lower Fence	0	-1.903	0	-5	0	-166	-1	0	-0.100	0	-52	-3	-45	-10	0	-0.99	-4	0	-0.54	-22	-5	-0.089
Upper Fence	0	7.233	0	13	0	710	3	0	0.438	0	182	15	169	30	0	3.73	20	0	2.4	80	25	0.385
Median	0	1.126	0	4	0	71	0	0	0.035	0	34	0	25	5	0	0.51	4	0	0.23	14	4	0.045
Caenozoic																						
1st quartile	0	0.204	0	1	0	11	0	0	0.010	0	9	0	7	3	0	0.14	0	0	0.02	3	0	0.005
3rd quartile	0	1.513	0	6	0	92	0	0	0.055	0	44	3	43	8	0	0.64	6	0	0.3	18	5	0.059
Lower Fence	0	1.003	0	4	0	65	0	0	0.030	0	22	3	26	1	0	0.29	6	0	0.25	11	5	0.047
Upper Fence	0	3.578	0	14	0	219	0	0	0.128	0	101	8	101	17	0	1.46	15	0	0.73	42	13	0.143
Median	0	1.258	0	5	0	78	0		0.043	0	33	3	34	6	0	0.47	6	0	0.28	14	5	0.053
Katanga																						
1st quartile	0	0.743	0	2	0	42	0	0	0.020	0	23	1	17	4	0	0.58	0	0	0.12	8	4	0.043
3rd quartile	0	4.783	0	6	0	310	2	14	0.245	0	82	14	98	24	0	3.55	10	0	1.18	35	25	0.415
Lower Fence	0	2.925	0	1	0	205	2	14	0.195	0	25	12	56	14	0	2.1	10	0	0.89	15	15	0.308
Upper Fence	0	11.213	0	13	0	733	5	35	0.593	0	182	34	228	55	0	8.28	25	0	2.82	80	59	0.995
Median	0	3.854	0	4	0	258	2	14	0.220	0	53	13	77	19	0	2.82	10	0	1.03	25	20	0.361
Basement																						
1st quartile	0	1.119	0	2	0	123	0	0	0.020	0	37	0	11	3	0	0.26	5	0	0.43	13	3	0.020
3rd quartile	0	3.894	0	6	0	772	1	0	0.340	0	159	4	93	10	0	0.97	12	0	2.13	71	9	0.126
Lower Fence	0	1.097	0	1	0	465	1	0	0.290	0	67	4	66	3	0	0.32	-1	0	1.06	39	2	0.076
Upper Fence	0	8.615	0	13	0	1808	3	0	0.830	0	361	10	222	23	0	2.17	25	0	4.9	165	20	0.296
Median	0	2.506	0	4	0	619	1	0	0.315	0	113	4	79	7	0	0.65	9	0	1.6	55	6	0.101

FA, fire assay.

*(Continued on next page)*

**Table 3 (continued) A summary of the analytical data with samples subdivided based bedrock geology**

Element	Mn ICP40 4ppm	Mo ICP40 2ppm	Na ICP40 0.005%	Nb ICP40 4ppm	Nd ICP40 9ppm	Ni ICP40 3ppm	P ICP40 0.005%	Pb ICP40 4ppm	Pd FA 1ppb	Pt FA 10ppb	Sc ICP40 2ppm	Sn ICP40 5ppm	Sr ICP40 2ppm	Ta ICP40 40ppm	Th ICP40 6ppm	Ti ICP40 0.005%	U ICP40 100ppm	U XRF 2ppm	V ICP40 2ppm	Y ICP40 2ppm	Yb ICP40 1ppm	Zn ICP40 2ppm
<b>All data</b>																						
1st quartile	34	0	0.000	0	0	0	0.005	0	0	0	0	0	2	0	0	0.155	0	0	9	3	0	3
3rd quartile	148	0	0.143	8	28	16	0.030	5	5	0	6	0	20	0	13	0.362	0	3	50	15	2	14
Lower Fence	-108	0	-0.072	-4	-14	-8	-0.020	-2.5	-3	0	-3	0	-12	0	-6.5	-0.336	0	-1.5	-34	-11	-1	-10
Upper Fence	336	0	0.358	20	70	40	0.070	12.5	13	0	15	0	48	0	32.5	0.750	0	7.5	116	35	5	32
Median	65	0	0.020	5	11	6	0.010	0	2	0	3	0	7	0	6	0.240	0	0	17	7	0	6
<b>Caenozoic</b>																						
1st quartile	29	0	0.000	0	0	0	0.000	0	0	0	0	0	0	0	0	0.144	0	0	7	2	0	3
3rd quartile	92	0	0.030	7	14	9	0.010	0	4	0	3	0	8	0	8	0.307	0	0	24	8	1	8
Lower Fence	20	0	0.030	7	14	9	0.010	0	4	0	3	0	8	0	8	-0.053	0	0	7	3	1	1
Upper Fence	201	0	0.075	18	35	23	0.025	0	10	0	8	0	20	0	20	0.623	0	0	53	18	2.5	17
Median	61	0	0.030	7	14	9	0.010	0	4	0	3	0	8	0	8	0.225	0	0	16	6	1	6
<b>Katanga</b>																						
1st quartile	54	0	0.010	0	0	6	0.010	0	0	0	2	0	5	0	0	0.192	0	0	18	5	0	6
3rd quartile	364	0	0.178	8	32	33	0.045	5	6	0	11	0	19	0	13	0.450	0	3	112	17	3	29
Lower Fence	230	0	0.153	8	32	18	0.020	5	6	0	6	0	7	0	13	-0.030	0	3	67	5	3	14
Upper Fence	855	0	0.435	20	80	77	0.103	12.5	15	0	26	0	43	0	32.5	0.933	0	7.5	262	38	7.5	67
Median	297	0	0.166	8	32	26	0.033	5	6	0	9	0	13	0	13	0.321	0	3	90	11	3	22
<b>Basement</b>																						
1st quartile	36	0	0.033	0	12	0	0.005	0	0	0	2	0	8	0	8	0.156	0	0	10	8	0	3
3rd quartile	109	0	0.354	9	55	11	0.025	8	4	10	5	0	96	0	34	0.324	0	6	33	24	3	8
Lower Fence	19	0	0.272	9	25	11	0.013	8	4	10	0	0	76	0	14	-0.066	0	6	8	4	3	1
Upper Fence	237	0	0.852	23	126	28	0.058	20	10	25	11	0	232	0	77	0.654	0	15	73	52	7.5	
Median	73	0	0.313	9	40	11	0.019	8	4	10	4	0	86	0	24	0.240	0	6	22	16	3	6

FA, fire assay.

**Table 4** Chemical analyses of the different sieve fractions from the first orientation survey of the sample collected immediately downstream of the Luamata Cu prospect

Element	Sieve fraction (mesh (#))						
	<8>16	<16>30	<30>60	<60>100	<100>150	<150>240	< 240
Au	< 8 ppm	< 8 ppm	< 8 ppm	< 8 ppm	< 8 ppm	< 8 ppm	< 8 ppm
Li	42 ppm	37 ppm	37 ppm	37 ppm	37 ppm	37 ppm	39 ppm
Be	2 ppm	1 ppm	1 ppm	1 ppm	1 ppm	1 ppm	1 ppm
Na	0.021%	0.016%	0.017%	0.017%	0.016%	0.016%	0.019%
Mg	0.760%	0.639%	0.628%	0.618%	0.611%	0.635%	0.697%
Al	4.581%	4.197%	4.090%	4.159%	4.033%	4.325%	4.822%
P	0.089%	0.084%	0.086%	0.084%	0.085%	0.084%	0.092%
K	1.53%	1.10%	1.01%	1.08%	0.97%	1.05%	1.21%
Ca	0.220%	0.294%	0.339%	0.318%	0.344%	0.349%	0.362%
Sc	13 ppm	11 ppm	11 ppm	11 ppm	11 ppm	12 ppm	13 ppm
Ti	0.238%	0.226%	0.233%	0.244%	0.264%	0.321%	0.317%
V	252 ppm	227 ppm	207 ppm	198 ppm	187 ppm	187 ppm	200 ppm
Cr	116 ppm	128 ppm	89 ppm	80 ppm	101 ppm	32 ppm	39 ppm
Mn	389 ppm	340 ppm	390 ppm	411 ppm	437 ppm	437 ppm	429 ppm
Fe	7.91%	6.57%	5.51%	5.11%	4.60%	4.24%	4.15%
Co	231 ppm	221 ppm	225 ppm	227 ppm	222 ppm	220 ppm	221 ppm
Ni	126 ppm	108 ppm	103 ppm	94 ppm	94 ppm	93 ppm	96 ppm
Cu	487 ppm	473 ppm	506 ppm	476 ppm	517 ppm	538 ppm	571 ppm
Zn	28 ppm	25 ppm	28 ppm	26 ppm	26 ppm	27 ppm	29 ppm
Ga	18 ppm	9 ppm	11 ppm	13 ppm	13 ppm	12 ppm	14 ppm
As	20 ppm	26 ppm	< 10 ppm	< 10 ppm	< 10 ppm	< 10 ppm	< 10 ppm
Sr	20 ppm	19 ppm	19 ppm	19 ppm	19 ppm	20 ppm	22 ppm
Y	20 ppm	18 ppm	18 ppm	19 ppm	18 ppm	20 ppm	22 ppm
Nb	< 4 ppm	< 4 ppm	< 4 ppm	< 4 ppm	5 ppm	6 ppm	8 ppm
Mo	5 ppm	3 ppm	< 2 ppm	< 2 ppm	3 ppm	< 2 ppm	< 2 ppm
Ag	< 2 ppm	< 2 ppm	< 2 ppm	< 2 ppm	< 2 ppm	< 2 ppm	< 2 ppm
Cd	< 2 ppm	< 2 ppm	< 2 ppm	< 2 ppm	< 2 ppm	< 2 ppm	< 2 ppm
Sn	< 5 ppm	< 5 ppm	< 5 ppm	< 5 ppm	< 5 ppm	10 ppm	9 ppm
Ba	317 ppm	267 ppm	261 ppm	269 ppm	265 ppm	284 ppm	327 ppm
La	73 ppm	74 ppm	81 ppm	84 ppm	85 ppm	99 ppm	119 ppm
Ce	180 ppm	170 ppm	183 ppm	202 ppm	192 ppm	224 ppm	267 ppm
Nd	55 ppm	64 ppm	72 ppm	75 ppm	76 ppm	91 ppm	108 ppm
Eu	3 ppm	3 ppm	3 ppm	3 ppm	3 ppm	4 ppm	4 ppm
Ho	< 4 ppm	< 4 ppm	< 4 ppm	< 4 ppm	< 4 ppm	< 4 ppm	< 4 ppm

low values of most elements. There are spot anomalies of one or two elements but nowhere are there any multi-element anomalies. In these areas, it will be relatively easy to detect pollution of the river systems.

#### Standard dataset for future mineral exploration the region

Tables 3–5 summarise the analytical results to provide a standard dataset for 42 elements for any future geochemical mineral exploration in central Africa where stream drain areas underlain by the three large geological units encountered in the Mwinilunga area. These three units cover much of western and central Zambia, southern Democratic Republic of Congo, north-western Botswana, eastern Angola and north-eastern Namibia.

#### Metal anomalies

##### The boxplot method

To define threshold values for anomalous values, the boxplot methodology was used.<sup>8</sup> In this, an upper

fence cut-off value is calculated as:

Upper fence =

$$3\text{rd percentile} + [1.5 \times (3\text{rd percentile} - 1\text{st percentile})]$$

Eq. (1)

Any values above the upper fence (cut-off) are regarded as anomalous within the given data set. Where more than one anomalous result is present within a regionally defined area, a regional anomaly can be inferred, which in many cases would warrant further work.

#### Copper (Table 6)

As the Mwinilunga area is prospective for copper and associated metals (within the western arm of the Lufilian Arc — the Copperbelt of Zambia and southern DRC), a plot is shown of the copper anomalies (Fig. 10). This plot highlights twelve significant anomalies around Mwinilunga. These include anomalies that can be related to known copper occurrences south of Mwinilunga, at and near the old copper workings at Luamata.

**Table 5** Internal XRAL standard (CANMET SO3 and TILL4) analyses

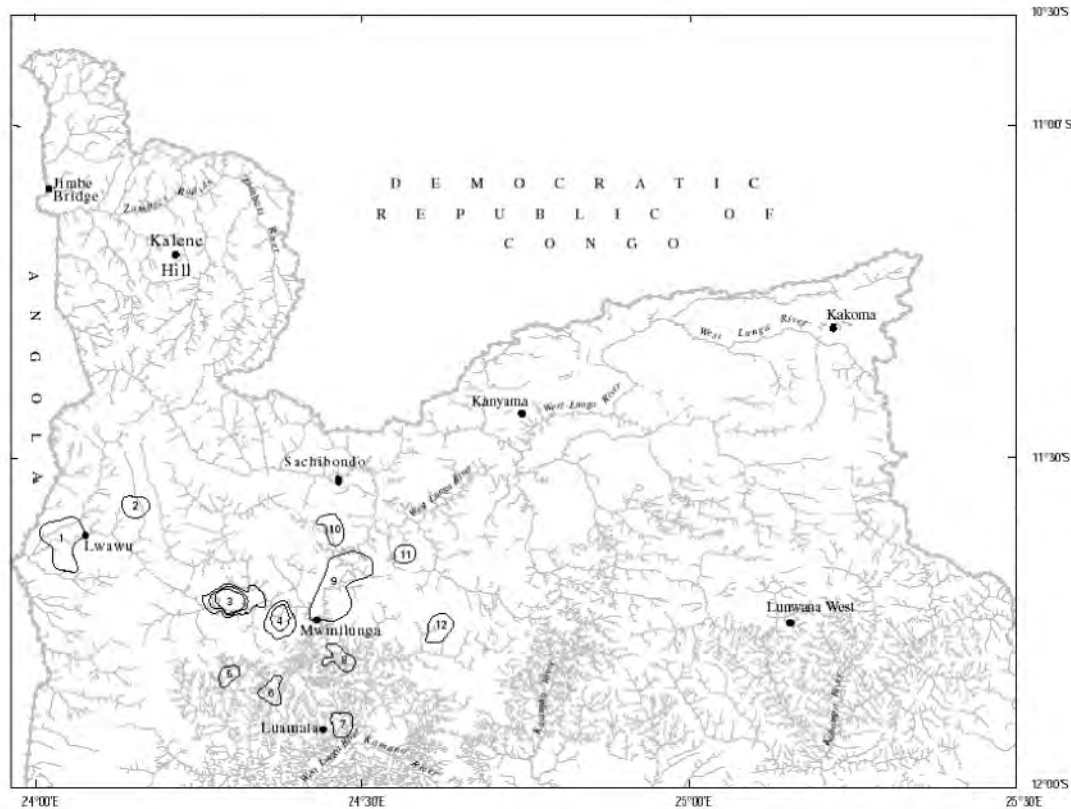
<b>Element</b>	<b>Au</b>	<b>Li</b>	<b>Be</b>	<b>Na</b>	<b>Mg</b>	<b>Al</b>	<b>P</b>
<b>Analysis type</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>
<b>Analysis unit</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>%</b>	<b>%</b>	<b>%</b>	<b>%</b>
<b>Detection limit</b>	<b>8</b>	<b>2</b>	<b>1</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>
SSO3	-8	13	-1	0.779	5.13	3.385	0.05
SSO3	-8	13	-1	0.765	5.058	3.34	0.05
Exp. value	-8	9	-1	0.74	5.07	3.05	0.048
STILL4	-8	31	3	1.8	0.702	7.835	0.095
Exp. value	-8	27	2.8	1.78	0.724	7.676	0.087
<b>Element</b>	<b>Ti</b>	<b>V</b>	<b>Cr</b>	<b>Mn</b>	<b>Fe</b>	<b>Co</b>	<b>Ni</b>
<b>Analysis type</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>
<b>Analysis unit</b>	<b>%</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>%</b>	<b>ppm</b>	<b>ppm</b>
<b>Detection limit</b>	<b>0.005</b>	<b>2</b>	<b>2</b>	<b>4</b>	<b>0.02%</b>	<b>2</b>	<b>2</b>
SSO3	0.178	41	14	512	1.56	4	12
SSO3	0.184	38	13	512	1.54	4	12
Exp. value	0.2	36	27	520	1.55	5.5	14
STILL4	0.466	77	31	451	3.99	7	14
Exp. value	0.479	77	45	440	3.706	8	14
<b>Element</b>	<b>Nb</b>	<b>Mo</b>	<b>Ag</b>	<b>Cd</b>	<b>Sn</b>	<b>Ba</b>	<b>La</b>
<b>Analysis type</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>
<b>Analysis unit</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>
<b>Detection limit</b>	<b>4</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>5</b>	<b>1</b>	<b>2</b>
SSO3	7	2	< 2	< 2	< 5	298	15
SSO3	6	3	< 2	< 2	< 5	292	16
Exp. value	6.4	2	< 2	< 2	< 5	296	16.9
STILL4	13	15	< 2	< 2	5	404	44
Exp. value	14	18	< 2	< 2	4	420	45
<b>Element</b>	<b>Ca</b>	<b>Sc</b>	<b>Eu</b>	<b>Ho</b>	<b>Yb</b>	<b>Ta</b>	<b>K</b>
<b>Analysis type</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>
<b>Analysis unit</b>	<b>%</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>%</b>
<b>Detection limit</b>	<b>0.005</b>	<b>2</b>	<b>2</b>	<b>4</b>	<b>1</b>	<b>40</b>	<b>0.01</b>
SSO3	14.5	5	< 2	< 4	2	< 40	1.29
SSO3	14	5	< 2	< 4	2	< 40	1.28
Exp. value	14.63	5.2	< 2	< 4	1.67	< 40	1.16
STILL4	0.895	10	< 2	< 4	2	< 40	2.61
Exp. value	0.929	12	< 2	< 4	1.97	< 40	2.52
<b>Element</b>	<b>Zn</b>	<b>Pb</b>	<b>Bi</b>	<b>Th</b>	<b>Nd</b>	<b>Y</b>	<b>Cu</b>
<b>Analysis type</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>
<b>Analysis unit</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>
<b>Detection limit</b>	<b>4</b>	<b>4</b>	<b>10</b>	<b>6</b>	<b>9</b>	<b>4</b>	<b>2</b>
SSO3	44	14	< 10	< 6	16	16	19
SSO3	42	12	< 10	< 6	16	16	19
Exp. value	48.3	13	< 10	< 6	17.2	16.4	17
STILL4	63	50	55	21	34	15	226
Exp. value	66	50	55	18	33	15	223
<b>Element</b>	<b>Ga</b>	<b>As</b>	<b>Sr</b>	<b>U</b>		<b>U</b>	<b>Ce</b>
<b>Analysis type</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>	<b>ICP40</b>		<b>XRF7</b>	<b>ICP40</b>
<b>Analysis unit</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>ppm</b>	<b>Analysis type</b>	<b>ppm</b>	<b>ppm</b>
<b>Detection limit</b>	<b>10</b>	<b>2</b>	<b>2</b>	<b>100</b>	<b>Analysis unit</b>	<b>2</b>	<b>5</b>
					<b>Detection limit</b>		
SSO3	18	< 10	218	< 100	SXRAL04	< 2	32
SSO3	7	< 10	216	< 100	SXRAL04	< 2	36
Exp. Value	6.4	< 10	222	< 100	Exp. Value	< 2	34
STILL4	18	109	105	< 100			93
Exp. Value	14.9	105	97	< 100			91

However, several new anomalies were discovered that are worthy of detailed follow-up investigations. Anomalies 1 and 2 in Figure 10 overlie andesitic and basaltic lavas in an area that Anglo-American explored in the 1990s for base metals. These two anomalies are the only ones where the underlying

Katanga bedrock is not intensely deformed within the Lufilian Arc. Anomalies 3 and 4 to the west of Mwinilunga have the highest copper values and are new discoveries. They occur in an area where thick Kalahari sediments overlie the Katanga bedrock. The high copper values were from samples collected from

**Table 6** A list of samples with anomalous base metal values. Locations given in Key *et al.*<sup>25</sup>

Base metal anomalies (samples in bold have more than one metal anomaly)									
Sample	Cu 2 (ppm)	Sample	Co 2 (ppm)	Sample	Ni 3 (ppm)	Sample	Cr 2 (ppm)	Sample	Zn 2 (ppm)
03DC0194	56	<b>03DC0074</b>	35	<b>03DC0074</b>	78	04DC3124	229	03DC0151	68
03DC0417	56	<b>03DC0427</b>	35	<b>04DC3093</b>	79	04DC3037	233	03DC0433	68
<b>03DC0107</b>	57	<b>04DC4179</b>	35	04DC4162	80	04DC3053	233	<b>03DC0649</b>	68
03DC0338	57	03DC0172	36	03DC0352	83	03DD3060	234	03DC0706	68
<b>03DD0007</b>	57	03DD0079	36	03DC0397	84	04DC4003	237	03DC0676	70
04DC3055	57	03DD0082	36	<b>03DD0083</b>	84	03DD3055	240	03DC0360	71
03DC0102	58	03DD0116	36	<b>03DD0120</b>	86	04DC3122	243	03DDK065	76
03DC0199	58	03DC0451	36	<b>03DD3032</b>	87	03DD0216	243	<b>03DC0458</b>	76
04DC4148	58	04DC2099	36	<b>03DC0051</b>	87	03DC0768	244	03DA0126	77
<b>03DC0175</b>	59	<b>03DC0055</b>	37	<b>03DD0087</b>	88	03DC0034	244	03DC0012	77
<b>03DC0658</b>	59	03DC0278	37	<b>03DD5004</b>	88	03DD4127	248	03DC0757	77
<b>03DC0451</b>	59	03DC0352	37	<b>04DC4121</b>	89	03DD0191	249	03DC0372	78
03DC0013	60	<b>03DC0399</b>	37	03DC0464	90	04DC3140	251	03DC0464	80
03DC0444	60	03DD4119	37	<b>03DC0457</b>	91	03DD0211	253	03DC0042	82
<b>04DC4179</b>	60	04DC2098	37	03DC0054	95	03DD2053	254	03DC0434	82
04DC3099	60	03DC0279	38	<b>03DC0055</b>	99	04DC3137	255	03DC0326	85
<b>03DC0221</b>	61	03DD0183	38	<b>03DC0001</b>	100	04DC3149	258	03DD1079	87
03DC0477	62	03DC0056	38	<b>03DD0184</b>	100	03DD3049	261	03DC0309	96
03DC0164	63	03DD3074	39	03DC0034	102	04DC3141	263	03DC0172	98
<b>03DC0420</b>	63	03DC0046	40	03DD1067	104	04DC3029	266	<b>03DC0376</b>	107
03DC0653	63	<b>03DC0615</b>	40	03DC0415	105	<b>04DC4121</b>	269	03DC0615	108
<b>03DC0055</b>	64	<b>03DC0175</b>	41	03DD1066	105	03DC0710	270	03DC0178	112
03DC0037	65	<b>03DC0221</b>	41	03DC0035	109	04DC3136	270	<b>03DC0396</b>	114
<b>03DC0614</b>	65	03DD0125	41	03DD3022	111	04DC3153	273	<b>03DC0616</b>	116
03DC0640	65	<b>03DD3032</b>	41	03DC0463	116	04DC3019	275	03DC0709	125
<b>03DC0051</b>	65	<b>03DD5004</b>	41	<b>03DC0399</b>	122	04DC3004	276	<b>03DC0612</b>	128
<b>03DC0654</b>	65	<b>03DC0654</b>	41	<b>03DC0353</b>	128	04DC3143	276	<b>03DC0463</b>	129
03DC0419	67	03DC0293	42	04DC2022	137	03DC0740	279	<b>03DC0494</b>	143
<b>03DD0120</b>	67	03DC0351	42	03DC0037	149	04DC3116	279	03DC0614	155
03DD3026	67	<b>03DD0007</b>	42	<b>03DC0458</b>	202	04DC3032	281	<b>04DC4179</b>	198
<b>03DC0353</b>	68	<b>03DD0120</b>	42			03DD0184	284	03DC0613	203
03DC0365	68	<b>03DC0612</b>	42			04DC3114	284	04DC4181	254
<b>03DD0087</b>	68	<b>03DC0107</b>	43			03DD3090	286	03DC0436	291
03DC0706	68	<b>03DC0052</b>	44			03DD0192	297	03DC0435	436
03DC0427	69	<b>03DC0437</b>	44			03DD4082	298		
03DD3025	69	<b>03DC0458</b>	45			04DC3048	300		
03DD0081	70	<b>03DC0616</b>	45			04DC3133	301		
03DD0122	70	<b>03DC0396</b>	45			04DC3042	321		
03DC5002	70	03DC0049	46			04DC3120	324		
03DC0156	71	<b>03DC0420</b>	47			03DD4074	353		
03DC0447	72	03DC0267	47			04DC3044	372		
03DC0233	74	<b>03DD0087</b>	48			03DD3078	390		
<b>03DD0083</b>	76	<b>03DC0614</b>	49			03DD4068	408		
03DC0450	76	<b>03DD0184</b>	49			03DC0761	608		
03DA0029	78	03DC0025	50			03DC0709	1090		
03DC0449	78	<b>03DD0083</b>	52						
03DC0430	79	<b>03DC0161</b>	53						
03DC0231	80	03DC0613	58						
03DC0434	80	03DB0546	59						
<b>03DC0458</b>	82	<b>03DC0649</b>	62						
<b>03DC0376</b>	82	<b>03DC0463</b>	63						
03DC0228	83	<b>03DC0457</b>	65						
03DD0190	86	03DD1025	74						
<b>03DC0457</b>	87	<b>04DC3093</b>	82						
03DC0644	91	<b>03DC0007</b>	86						
03DC0173	92	03DC0268	101						
03DD1033	99	<b>03DC0428</b>	105						
03DC0044	101	03DC0622	108						
03DC0163	101	03DC0419	115						
03DC0162	102	<b>03DC0658</b>	121						
03DC0642	102	<b>03DC0001</b>	206						
03DC0497	105								
03DC0426	106								
<b>03DC0615</b>	112								
03DC0431	114								
03DC0160	131								
03DC0536	148								
<b>03DC0494</b>	155								
03DD1025	165								
<b>03DC0052</b>	169								
03DD0082	185								
<b>03DC0161</b>	225								
<b>03DC0007</b>	231								
<b>03DC0428</b>	255								
03DC0152	295								
03DC0105	325								
03DC0059	366								
03DC0423	395								
<b>03DC0001</b>	536								
<b>03DC0437</b>	1930								



10 Krig plot of copper values showing the 12 anomalies detected around Mwinilunga

the Musangila Stream where there are no surface signs of copper mineralisation. Anomalies 5–8 co-incide with known copper showings, including Luamata (Anomaly 7), in Katanga metasedimentary strata. The

fact that the present survey did detect these known anomalies confirms the high quality of the sampling programme and subsequent chemical analyses. Anomaly 9 has an arcuate shape, north from Mwinilunga that

Table 7 A list of samples with anomalous precious metal anomalies. Sample locations given in Key *et al.*<sup>25</sup>

Precious metal anomalies (samples in bold have more than one metal anomaly)									
Sample	Au (ppb)	Sample	Au (ppb)	Sample	Pt (ppb)	Sample	Pd (ppb)	Sample	Pd (ppb)
03DC0025	15	03DC0437	18	<b>03DDK194</b>	26	03DC0259	16	03DD0217	20
03DC0295	15	03DC0781	18	04DC3099	26	03DDK131	16	03DD3034	20
03DD2036	15	04DC2025	18	03DD4095	27	<b>03DC0157</b>	16	03DD3050	21
03DD4210	15	<b>03DC0267</b>	19	04DC4042	27	04DA2088	16	03DD3067	21
04DC4044	15	03DDK033	19	03DD4163	28	03DC0587	16	03DD3023	22
<b>03DD3060</b>	15	03DD1021	19	04DC0046	28	03DC0781	16	03DD3036	22
<b>03DD3061</b>	15	03DC0333	20	03DD4132	29	<b>03DC0274</b>	17	<b>03DC0330</b>	22
03DC0711	15	<b>03DDK221</b>	20	03DD4125	30	<b>03DC0267</b>	17	03DC0090	23
<b>03DC0524</b>	15	04DA3000	21	04DC4014	30	03DD3056	17	03DD3053	23
04DC4014	15	03DD4164	22	<b>03DC0330</b>	31	03DD3062	17	03DD3046	26
<b>03DDK093</b>	15	<b>03DC0274</b>	23	<b>03DC0303</b>	32	03DD4107	17	<b>03DD3027</b>	26
03DDA060	16	03DC0005	24	<b>03DC0310</b>	32	03DC0331	17	03DC0310	28
<b>03DDK059</b>	16	03DDA062	26	<b>03DDK093</b>	34	03DD3051	18	03DC0016	29
03DC0785	16	03DC0037	27	<b>03DDK221</b>	34	03DD3022	18	03DC0303	36
<b>03DD3073</b>	16	04DC0507	27	04DC0050	37	<b>03DDK093</b>	18	03DDA041	41
<b>04DC4015</b>	16	03DDK195	32	<b>03DDA041</b>	38	03DDK221	18	<b>03DC0017</b>	68
03DDK056	16	<b>03DC0305</b>	33			03DC0031	19		
<b>03DDK099</b>	16	03DD0202	44			03DD3032	19		
03DC0308	16	04DC4075	44			03DC0706	19		
<b>03DDK194</b>	16	<b>03DDA041</b>	44			<b>03DDK099</b>	19		
<b>03DC0303</b>	16	04DC2120	52			03DD0216	19		
<b>03DD3119</b>	17	<b>03DC0017</b>	72			03DD3026	20		
<b>03DD3027</b>	17	<b>03DC0310</b>	87			03DC0304	20		

**Table 8** A list of samples with anomalous uranium values. Sample locations given in Key *et al.*<sup>25</sup>

Sample	Uranium (ppm)
04DC4129	16
03DA0246	17
04DC3133	17
03DA0277	18
04DC3130	18
04DC4130	18
04DC3132	18
03DD2043	19
04DC3094	19
04DC4198	20
03DA0278	22
03DA0176	23
03DA0265	25
03DA0273	25
03DA0275	41
03DA0264	45
04DC3027	67

reflects the Katanga bedrock structure. Anomaly 10 reflects high values from six samples collected from one west-bank tributary of the West Lunga River south of Sachibondo. Anomaly 11, about 10 km east of Anomaly 10, is defined by a single high value in an east-bank tributary of the West Lunga River. Finally, Anomaly 12 is defined by high values in several samples collected from a north-bank tributary of the Nyangombe River.

Anomalies 3–12 directly underlain by Katanga bedrock have two obvious trends – ~N to NNE for the whole group, and NW–SE. The second trend is shown by the alignment of four groups of anomalies (3, 4 and 8; 5, 6 and 7; 9 and 12; 10 and 11). A structural analysis of the Luamata mineralisation also picked up a strong NW–SE structural control on the copper mineralisation.<sup>29</sup>

An analysis<sup>24</sup> of the copper values in stream sediments from the Chief Sailunga area indicated a strong local control (including Anomaly 12) by NE-trending faults or shears.

#### Precious metals

Over 80 samples were found to have anomalous values of one or more of the three analysed precious metals (Table 7). In most cases, the anomalous samples are single analyses and they were found in all three geological domains. However, a cluster of 5 gold anomalies is centred near GR 35L 2690 87100 where there appears to be a strong control by NE-trending lineaments on the sampled drainage channels. This is an area underlain by Caenozoic sediments and the source of the gold is unknown. No visible gold was noted during the fieldwork.

#### Uranium

About 20 samples contained anomalous uranium values (Table 8). There are two clusters (samples 03DA0246 and 0176, and samples 03DA0164, 0273, 0275, 0277 and 0278) of high uranium values in

streams draining the equigranular granite of the Kasai Shield. Other high uranium values were found from samples collected in the eastern part of the area in streams draining pre-Katanga basement exposed in the core of the Kabompo Dome. Here, five weak uranium anomalies were found although none correspond with the uranium anomalies found by Agip<sup>1–4</sup> during its exploration in the early 1980s. However, one of the anomalies (03DD4055) is from an area underlain by basal Katanga quartzite and its granitic basement (the setting of the anomalies found by Agip). The other four anomalies occur in areas of Katanga bedrock and three are clustered around GR 2330 86935 where there are marble exposures.

#### Lanthanum, cerium, neodymium, yttrium, ytterbium and thorium

A large number of anomalous values for these elements were detected (Table 9). Over 30 samples contained anomalous values of four or more of these elements and two samples (03DA0264 and 04DC3027) had anomalous values for all these elements. The vast majority of these anomalies are clustered over the pre-Katanga basement or in the immediately overlying basal Katanga sediments (in the Kabompo Dome). The equigranular granite mapped in the Kasai Shield underlies a number of the anomalies. Further work is clearly warranted on this granite, which also underlies samples with high uranium values. Anomalous samples in the Kabompo Dome are associated with different lithologies including granite, gneiss and schist and there is a local fault or shear control on these anomalies.<sup>28</sup>

#### CONCLUSIONS

- (i) The geochemical database from analysed stream sediment samples in NW Zambia provides a baseline that can be used to monitor pollution of stream sediments throughout central Africa. This is because the study areas is underlain by three major bedrock types that are extensively developed in this part of the continent, namely crystalline basement, a 'Pan African' orogenic belt, and Kalahari Group sediments. The geochemical signature of each of these 'provinces' based on analyses of more than 40 elements is documented. The study area is unpolluted as no signs of any form of pollution were noted during the fieldwork. Hence the database can confidently be stated to provide the range of chemistry found naturally in stream sediments of central Africa.
- (ii) The database can also be a standard for future stream sediment geochemical exploration in central Africa as it was prepared using recommended collection methods with tightly controlled multi-element analyses.
- (iii) The stream sediment sampling was successful in targeting a number of metal anomalies that warrant follow-up exploration. New anomalies of copper, precious metals, uranium and rare elements were located.



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### Author Queries

The style is: up to 6 authors in full; if more, first 6 then *et al.* Please see refs 10–13, 24–27, 29, 48

45. WATTS, GRIFFIS and MCQUAT: Authors' initials?