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OCCURRENCE OF GOLD IN HARDPAN, YOUANMI MINE

A.Z. Gedeon and C.R.M. Butt

CRC LEME OPEN FILE REPORT 36

September 1998

(CSIRO Division of Exploration Geoscience Report 23R, 1989.
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CRC LEME is an unincorporated joint venture between The Australian National University, University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining
Headquarters: CRC LEME c/o CSIRO Exploration and Mining, Private Bag, PO Wembley, Western Australia, 6014

RESEARCH ARISING FROM CSIRO/AMIRA REGOLITH GEOCHEMISTRY PROJECTS 1987-1993

In 1987, CSIRO commenced a series of multi-client research projects in regolith geology and geochemistry which were sponsored by companies in the Australian mining industry, through the Australian Mineral Industries Research Association Limited (AMIRA). The initial research program, "Exploration for concealed gold deposits, Yilgarn Block, Western Australia" (1987-1993) had the aim of developing improved geological, geochemical and geophysical methods for mineral exploration that would facilitate the location of blind, buried or deeply weathered gold deposits. The program included the following projects:

P240: Laterite geochemistry for detecting concealed mineral deposits (1987-1991). Leader: Dr R.E. Smith.
Its scope was development of methods for sampling and interpretation of multi-element laterite geochemistry data and application of multi-element techniques to gold and polymetallic mineral exploration in weathered terrain. The project emphasised viewing laterite geochemical dispersion patterns in their regolith-landform context at local and district scales. It was supported by 30 companies.

P241: Gold and associated elements in the regolith - dispersion processes and implications for exploration (1987-1991). Leader: Dr C.R.M. Butt.
The project investigated the distribution of ore and indicator elements in the regolith. It included studies of the mineralogical and geochemical characteristics of weathered ore deposits and wall rocks, and the chemical controls on element dispersion and concentration during regolith evolution. This was to increase the effectiveness of geochemical exploration in weathered terrain through improved understanding of weathering processes. It was supported by 26 companies.

These projects represented "an opportunity for the mineral industry to participate in a multi-disciplinary program of geoscience research aimed at developing new geological, geochemical and geophysical methods for exploration in deeply weathered Archaean terrains". This initiative recognised the unique opportunities, created by exploration and open-cut mining, to conduct detailed studies of the weathered zone, with particular emphasis on the near-surface expression of gold mineralisation. The skills of existing and specially recruited research staff from the Floreat Park and North Ryde laboratories (of the then Divisions of Minerals and Geochemistry, and Mineral Physics and Mineralogy, subsequently Exploration Geoscience and later Exploration and Mining) were integrated to form a task force with expertise in geology, mineralogy, geochemistry and geophysics. Several staff participated in more than one project. Following completion of the original projects, two continuation projects were developed.

P240A: Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia (1991-1993). Leaders: Drs R.E. Smith and R.R. Anand.
The approach of viewing geochemical dispersion within a well-controlled and well-understood regolith-landform and bedrock framework at detailed and district scales continued. In this extension, focus was particularly on areas of transported cover and on more complex lateritic environments typified by the Kalgoorlie regional study. This was supported by 17 companies.

P241A: Gold and associated elements in the regolith - dispersion processes and implications for exploration. Leader: Dr. C.R.M. Butt.
The significance of gold mobilisation under present-day conditions, particularly the important relationship with pedogenic carbonate, was investigated further. In addition, attention was focussed on the recognition of primary lithologies from their weathered equivalents. This project was supported by 14 companies.

Although the confidentiality periods of the research reports have expired, the last in December 1994, they have not been made public until now. Publishing the reports through the CRC LEME Report Series is seen as an appropriate means of doing this. By making available the results of the research and the authors' interpretations, it is hoped that the reports will provide source data for future research and be useful for teaching. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authorisation to publish these reports. It is intended that publication of the reports will be a substantial additional factor in transferring technology to aid the Australian Mineral Industry.

This report (CRC LEME Open File Report 36) is a first revision of CSIRO, Division of Exploration Geoscience Restricted Report 023R, first issued in 1989, which formed part of the CSIRO/AMIRA Project P241.

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PREFACE

The CSIRO-AMIRA project "Exploration for Concealed Gold Deposits, Yilgarn Block, Western Australia" has as its overall aim the development of improved geological, geochemical and geophysical methods for mineral exploration that will facilitate the location of blind, concealed or deeply weathered gold deposits.

This Report presents results of research conducted as part of Module 2 of this project (AMIRA Project 241):

"Gold and Associated Elements in the Regolith - Dispersion Processes and Implications for Exploration".

An objective of this Module is to obtain a better understanding of the nature of supergene gold deposits and to increase knowledge of the properties of the regolith in which they occur. The aim of the study reported herein was to determine the mode of occurrence of gold in the red-brown hardpan that formed the surface horizon over the Youanmi gold mine. The hardpan itself represented a moderate gold resource, with an average grade of 1 g/t, and the purpose of the investigation was to deduce the manner in which the gold enrichment of this essentially transported material had occurred. In the event, very few grains of gold were located and it is inferred that the gold is present mostly as very fine particles ($<1\ \mu m$) below the effective detection limit of the electron-optical techniques employed. However, the study did provide an opportunity for the examination of the hardpan itself.

C. R. M. Butt
February 1990

OCCURRENCE OF GOLD IN HARDPAN, YOUANMI MINE

A. Z. Gedeon and C. R. M. Butt

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ABSTRACT

Geochemical, mineralogical and petrological studies of the red-brown hardpan forming the surface horizon at the Youanmi gold mine were undertaken to determine the form and origin of the gold within it. The hardpan itself, apparently typical of the Wiluna Hardpan that occurs extensively in the Murchison District, is a silica-cemented unit across the transition from saprolite (in situ weathered bedrock) to colluvium (locally transported sheetwash deposit). Passing upwards, it consists of fractured saprolite, untransported saprolite blocks and poorly sorted colluvial debris cemented by a porous, red-brown matrix. The matrix contains apparently clastic clay, silt and sand-sized fragments and aggregates in a silica cement; translucent orange and clear silica (hyalite) forms a coating on the walls of fractures and voids. Despite the heterogeneity of the hardpan, the gold content appears to be fairly uniform within individual profiles. Four polished sections of hardpan were searched by scanning electron microscopy. Gold was found in only one section, in which four particles (1 to 3 microns) were located. These were all situated on open voids, which could be due to contamination during preparation or analysis of the samples, or to the late stage mobility of gold, either chemically or by physical illuviation. Gold probably also occurs throughout the hardpan matrix as very fine particles below the resolution of the scanning electron microscope.

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A. Z. Gedeon and C. R. M. Butt

INTRODUCTION

The Wiluna Hardpan and the equivalent red-brown hardpans are silicified near-surface horizons of the regolith present over wide areas of the arid interior of Australia. In Western Australia, hardpan is found mostly north of about latitude 30° S. The original definition of Wiluna Hardpan (Bettenay and Churchward 1974) described it as a silicified colluvium - that is a mechanically transported overburden that has subsequently been cemented by chemically precipitated silica. It commonly consists of poorly sorted fragments of quartz, weathered rock and ferruginous accumulations, including lateritic pisoliths, set in an earthy matrix, the whole being silicified though remaining porous. The material has a coarsely laminated appearance and commonly has a patchy coating of manganese oxide on partings. Recent open pit mining has permitted a closer examination of hardpan, particularly the lower contact, and it is evident that the descriptions and definition require modification. Near the surface, hardpan usually consists of detrital material such as that described by Bettenay and Churchward (1974), but may pass gradationally downwards into brecciated saprolite. The saprolite blocks generally retain their original orientation even though they appear to be surrounded by the reddish silica cement. Thus, it is probable that 'hardpan' should refer more to this characteristic cementation than to the substrate. Nevertheless, much hardpan does consist predominantly of transported overburden and as such it can be a considerable hindrance to exploration for mineralization lower in or beneath the regolith. However, some hardpan, such as that at Youanmi, contains gold and there is the possibility that some may have been emplaced after the deposition of the sediment. The objective of this study was to examine the hardpan and to attempt to deduce the mechanism of gold enrichment within it.

LOCATION OF STUDY AREA

The Youanmi open cut mine has been developed at the site of the old Youanmi underground mine which was closed in 1947. Youanmi is situated about 490 km NE of Perth, at latitude 28° 37' S, longitude 118° 49' E in the southern part of the Murchison District. Primary gold mineralization in the Youanmi mine is associated with quartz veins in felsic volcanics, tuffs and associated granitic rocks that form part of the Youanmi greenstone belt. Total production from the mine was about 0.75 million tonnes at an average grade of 11.44 g/t. The mine area extends from a low rise, the site of the old workings that included a small opencut, down a gentle slope to the south. At the top of the rise, there was only a thin veneer (<20 cm) of hardpan but this thickens to 2 - 3 metres in depth down slope. The substrate of the hardpan is mostly a coarse colluvium, merging downwards to brecciated felsic saprolite, apparently in situ; at the base of the slope, the hardpan contains poorly bedded pisoliths. Overall, the hardpan represented a moderate gold resource, with concentrations exceeding 1 g/t Au.

SAMPLING AND ANALYSIS

Sampling

Samples were collected from several vertical profiles through the hardpan in the vicinity of the subcropping mineralization. Samples were taken of the principal horizons visible on exposed faces on the pit walls from the surface to the saprolite at 2 - 3 m depth. Because of the highly heterogeneous nature of these materials, the samples can be considered to be only partly representative of the horizon from which they were derived. In selecting samples for analysis, attempts were made to separate the principal components, such as the cementing hardpan matrix, saprolite blocks and lithorelics. However, the heterogeneity is present at all scales from tens of centimetres to a millimetre or less, so that complete segregation was not possible. Samples were

analysed for gold by fire assay fusion and ICP-MS (Analytical Services Pty. Ltd.,) and for major and minor elements by ICP analysis following lithioborate fusion (CSIRO laboratory).

The bulk mineralogy of the samples was determined by X-ray powder diffractometry using Cu Kα radiation. The mineralogy of individual phases observed by optical and scanning electron microscope (SEM) was determined using a Debye-Scherrer camera (Ni-filtered Cu Kα radiation at 40 kV).

The locations and mineral association of individual gold particles was determined on uncoated polished sections of selected samples using a Jeol SEM in back-scattered electron mode, with identifications confirmed by analysis using an energy dispersive spectrometer. The technique is capable of finding grains with a minimum diameter of one micrometre. This requires a magnification of 1000-fold, at which one screen of the TV monitor covers an area of approximately 0.2 x 0.26 mm. A 10 x 25 mm area can be scanned without repositioning, using about 5000 TV fields of view. At a concentration of 1 ppm and assuming an even distribution of gold, 250 mm^2 of a polished section can be expected to contain 34 grains one micrometre in diameter. This represents about 150 TV fields-of-view per grain.

NATURE OF THE HARDPAN.

Description of the profile

Hardpan was sampled at an early stage of mining, when a complete section 3 - 5 m thick from the surface to saprolite, was exposed in the walls in the upper part of the pit. Shallow excavations at the base of slope permitted sampling of the pisolithic material. A typical section through the hardpan is illustrated in Figure 1. Close examination demonstrates that the hardpan cannot be considered as a simple unit with a unique mineral assemblage or chemical composition. Rather, it is an extremely heterogeneous material that has ferruginous silica cement as a common attribute. The base of the hardpan, as indicated by the development of the typical red-brown staining, is within the saprolite and thus within the upper part of the partly truncated lateritic profile. From the base of the hardpan section, the saprolite becomes increasingly brecciated, with individual saprolite blocks separated by red-brown, apparently clastic, clay, silt and sand-sized fragments and aggregates in a silica cement. Despite a gradual decrease in size, the blocks appear to retain their original orientation, as indicated by cleavage and bedding directions, even when comprising only about 50% of the material. Higher still, settling due to greater alteration and some downslope movement have led to a gradual shallowing of the dip, loss of original orientation and finally the development of a poorly sorted, colluvial sediment containing weathered rock fragments in a matrix similar to the apparently clastic material separating the saprolite blocks at depth. This sedimentary horizon is essentially identical to Wiluna hardpan as described by Bettenay and Churchward (1974), with the typical coarse lamination and the development of manganese oxide coatings on surfaces. It is overlain by a thin (10 - 20 cm) soil, which resembles the hardpan itself but is unsilicified.

Petrography

Material from the base of the colluvial horizon, enriched in gold, was selected for detailed study.

In thin and polished section, three main components can be seen in the hardpan (Figures 2A, 2B, 2E and 2G):

1. Clasts, 1mm to several centimetres or more (lithic fragments, quartz, pisoliths).
2. Silicified, ferruginous silty clay matrix.
3. Translucent orange and clear silica cement.

Clasts: The coarse clasts in the sample are predominantly sub-angular to sub-rounded lithic fragments, mostly of white saprolite, consisting of kaolinite, rare fine grained quartz and iron oxide pseudomorphs after pyrite. Haloes of iron oxide impregnate and stain the kaolinite around the pseudomorphs. Thin quartz veinlets are present within or marginal to some fragments, locally with

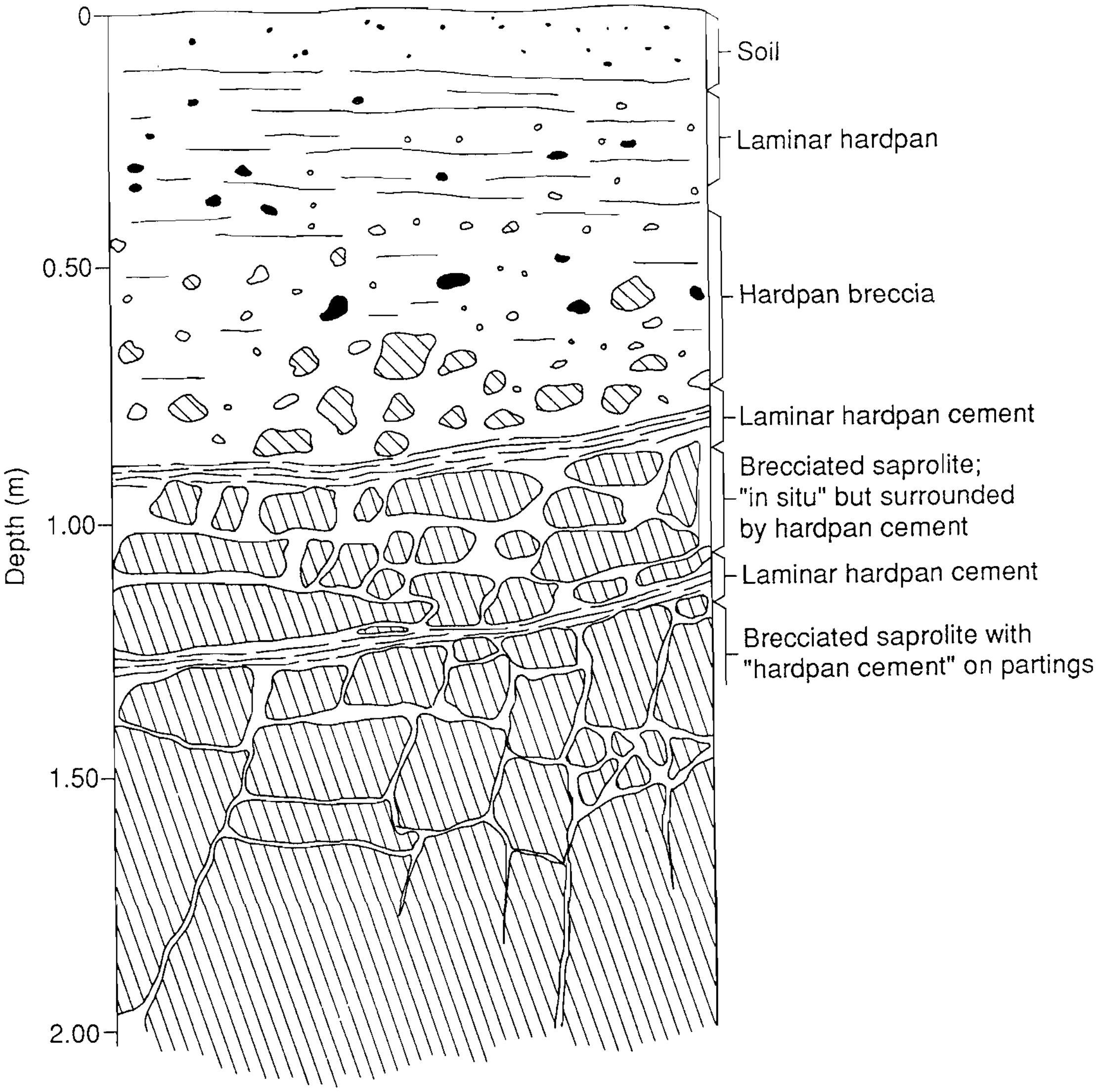

Figure 1. Section through typical hardpan profile, Youanmi goldmine, illustrating gradational contact between colluvium and saprolite.

associated coarse muscovite (apparently a resistant primary mineral). A poorly crystalline or amorphous material, either an aluminosilicate or, more probably, silica, is present throughout the kaolinitic saprolite fragments, making them largely opaque. Iron oxides from the surrounding matrix invade and perhaps replace the kaolinite around the margins of the saprolite fragments. Some lithic fragments are more strongly ferruginized, but the relationship with the surrounding matrix is unclear.

Matrix: The silicified matrix consist of almost opaque, rounded, masses (commonly >0.5 mm in diameter) of kaolinitic clays, with some fine quartz, invaded by brown iron oxides and silica. The matrix mostly encloses the lithic fragments and penetrates cracks and fissures within and between them. Iron oxides associated with the matrix invade the lithic fragments and possibly partially replace them. However, it is clear that the matrix is at least partly detrital (ie emplaced by physical illuviation), containing minerals that are not present in the adjacent fragments, eg muscovite, or are present in greater abundance, eg quartz. The matrix itself may also be fragmented into slightly elongated blocks, aligned parallel to veining and layering. Some such blocks could be lithic fragments, although their silty clay texture, which is different from the others present in the sample, would imply a detrital (illuvial) origin.

Cement: The silica cement has two components:

a: opaline silica (hyalite) stained orange to orange-brown by iron oxides. Locally, the silica is banded parallel to the outlines of enclosed matrix blocks and lithic fragments, but shows an overall banding parallel to the laminations and veining shown by the elongated fragments and sub-horizontal pseudo-bedding of the bulk material. Some colour banding probably relates to changes in iron concentration. In detail, the silica has a colloform fabric and remains translucent under crossed nicols; there is a weak birefringence parallel to the banding, probably due to strain but also possibly due to included kaolinite.

b: clear opaline silica as a thin (commonly <1 mm) outer coating on void and fracture walls.

The orange silica (a, above) is the principal cement of the hardpan, surrounding lithic fragments and matrix, and penetrating along fractures in both, but apparently not invading or replacing either. The clear silica (b) only occurs as an outer coating and may have been precipitated much later.

Geochemistry of the hardpan.

Analytical data from samples collected at four sites in the vicinity of subcropping mineralization are given in Table 1. Samples were visually inspected prior to analysis and the proportion of lithic fragments minimized. At any scale, the material consists of an intimate mixture of fragments and cementing matrix (eg see Figures 2A and 2B) and segregation can at best be only partial; this is demonstrated by the similarity between compositions of carefully handpicked hardpan matrix and the original bulk samples (Table 2). Accordingly, the hardpan compositions are greatly influenced by the degree of inhomogeneity, both of the cementing matrix itself and of the matrix - lithic fragment mixture. The upward decrease in MgO and, in part, CaO contents in the profile at site A may reflect a decline in the abundance of fragments and/or stronger leaching of the fragments towards the surface. Few other trends are apparent in the data and most variations are probably due to changes in the abundance of lithic fragments and the degrees of silicification and ferruginization. Variations between sites could reflect differences in bedrock lithology. The greatest variations are shown by the abundance of Ba which shows some upward enrichment and is seen as secondary precipitates of barite during SEM examination. The abundance and variability of Mn, however, is less marked than expected, given the characteristic presence of manganese oxides precipitated on partings in the hardpan.

Gold appears to be evenly dispersed within the profiles, especially at sites A and C. Abundances appear to be different between sites - eg profile A, mean = 0.83 ppm Au; profile C, mean = 0.27 ppm Au. The highest value, 3.9 ppm Au, is from a single sample at site B about 10 m from the old main shaft of the mine. Given the bias of the sampling towards the cementing matrix of the hardpan, it is considered probable that most of the gold is present in this matrix rather than in the lithic fragments.

OCCURRENCE AND MINERALOGICAL ASSOCIATION OF GOLD

Determination of the location of gold within the cementing matrix was attempted by scanning electron microscopy of polished sections of three samples. The samples examined were numbers 00 4010 (two sections), 00 4015 and 00 4038. The bulk compositions of the samples are given in Table 1. Gold was found in sample 00 4015.

Sample 00 4015, bulk gold content = 0.73 ppm

Four gold grains were found (Figures 2C, 2D, 2F and 2H), with diameters of 1 - 3 μm. Each is located on the margin of a void, which must raise the possibility of contamination, for example during polishing. However, such a location is also plausible as a natural occurrence; furthermore, one grain (No. 2, Figure 2D) is angular, and all have remained in place despite the effects of charging during examination, which would cause loose grains to move. No silver was detected in grains 2 and 3; grains 1 and 4 were too small to be analyzed. The angularity of grain 2 and the absence of silver suggests that the gold grains are secondary. Each grain is associated with the clear silica coating the voids, whether these are in the cementing matrix (grains 1, 2 and 4) or in a bleached lithic fragment (grain 3). Grains 1 and 3 appear to be within the silica cement whereas grains 2 and 4 are on the void walls; however, the relationships are not certain.

The mineralogical associations of the grains were determined by qualitative analyses of the clearly different phases evident by SEM and subsequent XRD (Debye-Scherrer) of scratched powders. The powders, of course, are much less clearly defined than the spots analysed by SEM and hence may be mixtures. Furthermore, since much of the material is amorphous or nearly so, the XRD data only refer to phases that have significant crystallinity; they may not represent the most abundant phase. The combined results are given in Table 3.

Silica is dominant and the other elements are either adsorbed on it or included in it as very fine mineral phases that cannot be segregated at the resolution of the SEM electron beam. X-ray diffraction gave only very poorly resolved lines and the results support the analytical and petrographic evidence that the cementing material of the hardpan and the phase most closely associated with gold is amorphous or poorly crystalline silica, with minor kaolinite and iron oxides.

CONCLUSIONS

The results of this study are inconclusive as to the nature and occurrence of the gold because (1) only very few grains were observed and (2) of the possibility that the grains are the result of contamination during the course of sample preparation and handling. The angularity of the grains and their physical stability during SEM examination suggests that they are in their true location. Conversely, the absence of any evidence that the grains are embedded within any cement suggests contamination. If it is assumed that the grains are correctly located, their presence in voids coated with clear silica implies that gold has been mobile - either physically or chemically - at a very late stage in the formation of the hardpan. Such a conclusion is consistent with evidence from elsewhere in the Yilgarn Block, where gold is known to be enriched in surface horizons of otherwise barren transported overburden directly overlying mineralization. The gold would either have been precipitated in the void where it is found, or emplaced by illuviation. Such a conclusion does not, however, negate the possibility that gold enrichment did not also occur earlier in the development of the hardpan. Insufficient samples were examined for such a concluson to be drawn and it is possible that gold occurs as very much finer particles, or even as an adsorbed species, and hence is not detectable by these means.

The investigation was terminated because of its time-consuming nature and the equivocal results it was yielding.

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REFERENCE

Bettenay, E. and Churchward, H.M., 1974. Morphology and stratigraphic relationship of the Wiluna Hardpan in arid Western Australia. *J. Geol. Soc. Aust.*, **21**, 73-80.

	Sample Number	Depth m.	Au ppm	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	TiO_2 %	Mn ppm	Cr ppm	V ppm	Zr ppm	Ba ppm	Cu ppm
Site A															
Hardpan	00 4015	0.5:	0.73	62.8	19.4	5.43	0.76	0.53	0.41	85	145	120	50	210	40
Hardpan	00 4018	0.5:	1.00	61.3	17.8	5.38	0.87	0.60	0.41	130	130	95	45	165	35
Hardpan	00 4012	0.9:	0.89	63.8	18.6	5.09	1.03	0.53	0.42	80	145	115	46	125	45
Hardpan	00 4005	1.0:	0.53	59.8	18.1	5.54	1.19	0.44	0.40	85	150	105	39	105	45
Hardpan	00 4007	1.4:	0.35	56.2	19.7	7.10	1.49	0.37	0.64	360	240	200	50	95	65
Hardpan	00 4010	1.5:	1.00	60.8	18.1	6.38	1.43	0.35	0.57	225	260	175	46	170	120
Hardpan	00 4019	1.5:	1.30	59.8	14.9	4.21	2.43	2.73	0.45	110	160	120	28	70	40
Saprolite	00 4020	:		37.0	5.84	2.37	4.10	22.3	0.33	90	110	105	21	70	50
Site B															
Hardpan	00 4023	1.0:	3.90	66.8	13.3	6.51	1.74	0.725	0.42	145	180	135	34	620	65
Site C															
Hardpan	00 4028	0.5:	0.26	54.9	16.6	15.0	0.47	0.368	1.05	795	345	310	140	330	70
Hardpan	00 4026	0.9:	0.23	59.6	19.3	5.99	0.64	0.645	0.53	115	135	105	55	310	41
Hardpan	00 4030	3.5:	0.28	54.5	22.3	6.67	0.80	0.829	0.83	150	280	170	60	95	70
Saprolite	00 4032	3.5:	0.29	36.4	13.6	32.9	0.41	0.268	0.51	50	375	905	60	145	195
Site D															
Hardpan	00 4045	0.4:		63.2	15.0	11.9	0.22	0.126	1.33	450	290	270	215	185	55
Hardpan	00 4044	0.6:	0.65	63.3	13.3	5.08	0.46	0.574	0.57	390	135	145	65	5420	43
Hardpan	00 4043	0.7:	0.39	47.8	13.7	4.37	0.57	10.6	0.71	280	175	180	39	520	46
Hardpan	00 4041	1.2:		59.8	16.3	4.98	0.37	0.377	0.69	200	180	205	32	605	38
Hardpan	00 4042	1.2:		57.2	19.0	6.03	0.51	0.409	0.76	125	150	110	105	130	60
Hardpan	00 4039	1.7:	0.36	62.6	12.6	6.01	0.37	1.96	0.54	200	210	205	27	90	55
Hardpan	00 4038	1.9:	0.11	74.3	6.34	5.96	0.23	0.169	0.18	165	175	115	12	245	41
Grey clay	00 4037	2.0:	0.16	54.8	17.9	8.35	0.50	0.433	0.73	240	190	150	95	205	55
Saprolite	00 4033	2.5:		38.6	16.9	4.49	0.52	14.3	1.04	440	225	280	30	90	38

Table 1. Composition of hardpan and saprolite, Youanmi.

	Sample Number	Depth m.	Au ppm	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	TiO_2 %	Mn ppm	Cr ppm	V ppm	Zr ppm	Ba ppm	Cu ppm
Bulk	00 4010	1.5:	1.00	60.8	18.1	6.38	1.43	0.34	0.56	225	260	175	46	172	120
Matrix	00 4010			61.0	15.0	4.81	1.17	0.37	0.42	39	265	125	-	110	164
Bulk	00 4012	0.9:	0.89	63.8	18.6	5.09	1.03	0.53	0.42	80	145	115	46	125	45
Matrix	00 4012			60.6	16.0	4.53	0.832	0.47	0.37	56	125	100	-	227	12
Saprolite	00 4012			61.0	17.7	6.42	0.236	0.21	1.24	-	379	385	-	48	-
Bulk	00 4018	0.5:	1.00	61.3	17.8	5.38	0.869	0.60	0.41	130	130	95	46	165	35
Matrix	00 4018			58.5	17.3	5.31	0.819	0.69	0.34	100	110	65	-	65	-
Matrix	00 4018			59.9	16.5	4.70	0.966	0.67	0.30	115	110	47	-	200	-
Bulk	00 4023	1.0:	3.90	66.8	13.3	6.51	1.740	0.73	0.42	145	180	135	34	620	64
Matrix	00 4023			66.3	11.6	6.16	1.530	0.29	0.36	65	175	155	34	510	62
Bulk	00 4028	0.5:	0.26	54.9	16.6	15.0	0.471	0.37	1.05	795	345	310	140	330	70
Matrix	00 4028			58.8	15.0	13.8	0.386	0.35	1.06	865	345	320	165	1114	75
Bulk	00 4038	1.9:	0.11	74.3	6.34	5.96	0.231	0.17	0.18	165	175	115	12	245	41
Matrix	00 4038			75.9	11.60	7.38	0.384	0.29	0.32	213	215	200	33	135	70
Bulk	00 4044	0.6:	0.65	63.3	13.3	5.08	0.464	0.57	0.57	390	135	145	63	5420	43
Matrix	00 4044			73.7	9.82	3.35	0.329	0.96	0.39	160	110	120	35	210	31
Bulk	00 4046	1.2:		60.2	15.7	8.90	0.452	0.46	0.68	170	205	195	62	540	67
Matrix	00 4046			61.6	18.5	6.84	0.512	0.60	0.62	80	145	180	40	115	48

Table 2. Compositions of hardpan (as Table 1) and hardpan matrix from the same samples, segregated to minimize lithic fragments.

Grain	Spot	Composition (Relative abundance)	XRD Mineralogy
1	1	Si >> Al > Fe	
	2	Si >> Al > Ca > Fe	
	3	Si >> Al = Fe >> Ca > K	
	4	Si >> Al = Fe >> Ca > K	
2	1	Si >> Al > Fe >> Ca > K	kaolinite
	2	Si >> Fe > Al >> K > Ca	)
	3	Si >> Al > Fe >> K > Ca	) amorphous
	4	Si >> Al > Fe >> Ca > K	)
3	1	Si	quartz
	2	Si > Al > Fe > K > Ca	) kaolinite + amorph.
	3	Si > Al > Fe >> K > Ca	) Fe oxides
4	1	Si >> Al > Fe >> Ca = K	)
	2	Si >> Al > Fe >> Ca > K > Ti	) amorphous Fe
	3	Si > Al > K > Fe >> Ca	) oxides
	4	Si >> Al > Fe >> K > Ca	)

Table 3. Qualitative compositions and mineralogy of phases associated with gold particles (refer to Figures 2C, 2D, 2F and 2H for locations). Analysis by energy dispersive spectrometry, Jeol scanning electron microscope; mineralogy determined by XRD using a Debye-Scherrer camera on scratched powders.

Captions for Page 10 over

Figure Caption.

Figure 2. Photomicrographs of hardpan and gold grains.

A: Lithic fragments in a cementing matrix of silicified, ferruginous silty clay and orange hyalite (crossed nicols, field width 3520 μm)

B: As A, plane polarized light, 3520 μm field width.

C: Gold grain 1 (arrowed). SEM backscattered electron image; gold grain associated with void. Numbers indicate sites of spot analyses and Debye-Scherrer XRD samples (Table 3); field width 120 μm.

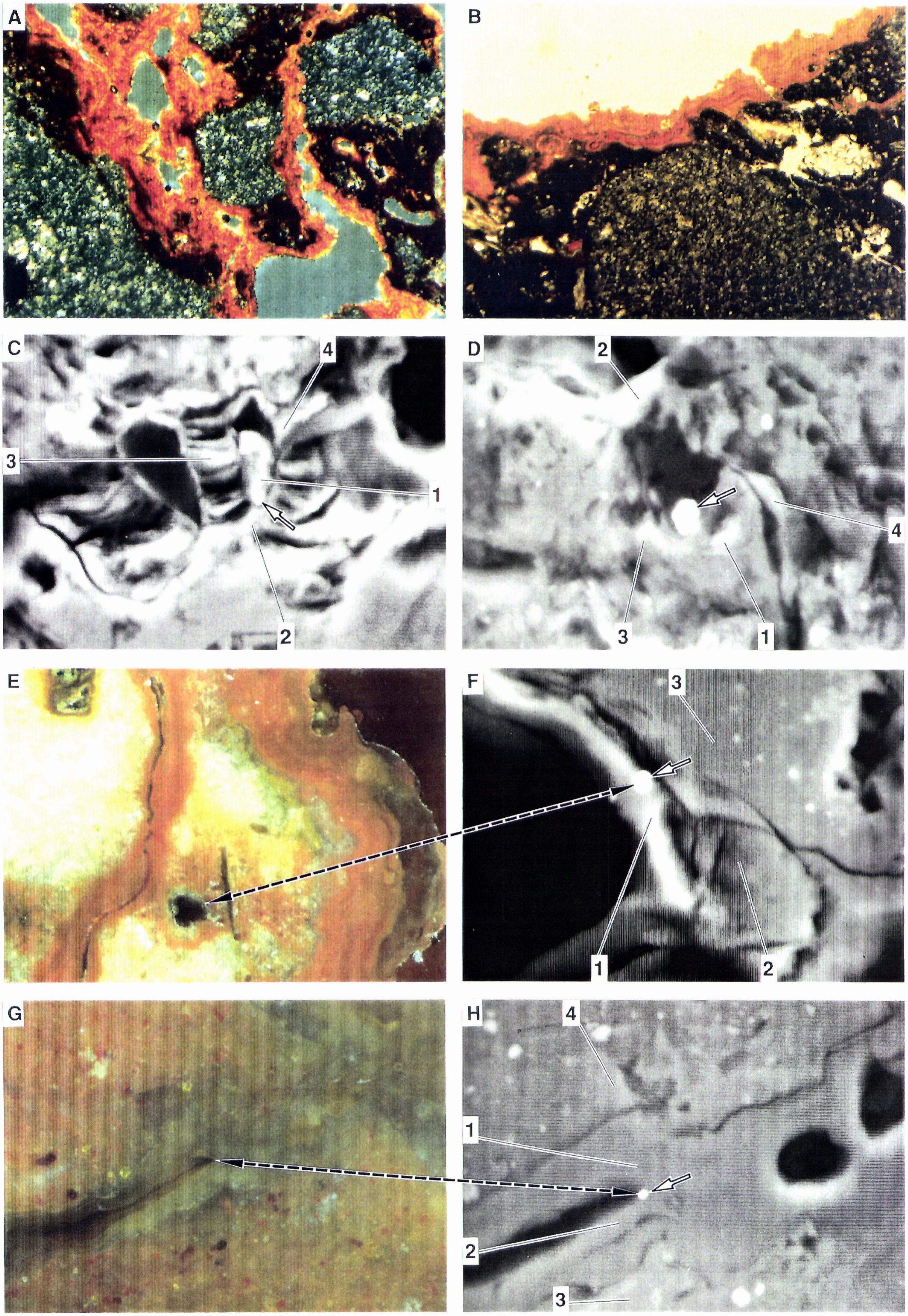
D: Gold grain 2 (arrowed). SEM backscattered electron image; gold grain associated with void in clear silica. Numbers indicate sites of spot analyses and Debye-Scherrer XRD samples (Table 3); field width 120 μm.

E: Lithic fragment with orange and clear hyalite coating cracks and surfaces. Lithic fragment contains quartz, kaolinite, muscovite and an iron oxide cast after pyrite. Void is location of gold grain 3 (see Figure 2F). Oblique reflected light, field width 1400 μm.

F: Gold grain 3 (arrowed), associated with clear hyalite in void in lithic fragment (see Figure 2E). SEM backscattered electron image, field width 120 μm. Numbers indicate sites of spot analyses and Debye-Scherrer XRD samples (Table 3).

G: Site of gold grain 4, associated with clear hyalite in a crack in silicified silty clay hardpan matrix. Oblique reflected light, field width 220 μm.

H: SEM backscattered electron image; gold grain 4 (arrowed) on hyalite partly infilling a void. Numbers indicate sites of spot analyses and Debye-Scherrer XRD samples (Table 3); field width 120 μm.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