BRAZIL GOLD'91, E.A. Ladeira (ed.) © 1991 Balkema, Rotterdam. ISBN 90 6191 195 8

Gold mobility during hydrothermal and supergene alteration of BIF (Itabirites), Ouro Fino syncline, Brazil

E. Ramanaidou
CSIRO, Division of Exploration Geosciences, Wembley, W.A., Australia & Laboratoire de Pétrologie de la Surface, Université de Poitiers, France

M. Cathelineau, J. Dubessy & M. Le Gleuher
CREGU and GS CNRS-CREGU, Vandoeuvre les Nancy, France

J.J. Trescases
Laboratoire de Pétrologie de la Surface, Université de Poitiers, France

Abstract : The Precambrian banded iron formation from the Quadrilatero Ferrifero and from the Ouro Fino syncline (Minas Gerais, Brazil) display some gold showings as quartz veins, and some gold anomalies in the surficial alteration facies.Fresh and altered rocks as well as quartz veins crosscutting the Ouro Fino series have been sampled in order to understand the factors controlling gold mobility in the itabirite series during hydrothermal vein formation, and during laterite formation. Fresh itabirites display rather high gold concentrations which range from 30 to 40 ppb. In laterites, the gold content remains relatively high but may vary significantly from the bottom to the top of the hills, and within the different horizons from 20 to 60 ppb Thus, fresh and altered itabirites may have constituted significant source rocks for gold. Systematic fluid inclusion studies by using microthermometry and Raman spectrometry analysis have been carried out on different types of quartz veins. At the hydrothermal stage, gold deposition seems to be restricted to the veins characterized by the presence of C-H-O-S fluids characterized by rather low fO2 (around that fixed by the Ni-NiO oxygen buffer) whilst no gold was found in the quartz-specularite veins characterized by high fO2 (fO2 greater than that fixed by the Hematite-magnetite buffer) and sulfate rich solutions.

1 INTRODUCTION

The Quadrilatero Ferrifero (Iron Quadrangle) of Minas Gerais (Brazil) owes its name to an almost rectangular arrangement of huge banded iron-formations or BIF (Dorr, 1969 ; Hoppe et al., 1987). The Quadrilatero Ferrifero is an area of about 7000 km^2 of central Minas Gerais located approximately 450 km north of Rio De Janeiro (Fig. 1). The area is rich in mineral deposits of Au, Mn and Al (Abreu, 1973). The itabirites (BIF) are in places gold bearing, and are enriched by decomposition (Siegers and Renger, 1985).

This paper reports a study of gold concentrations in fresh and weathered itabirites and the factors controlling gold mobility in the Ouro Fino syncline situated in the central part of the Quadrilatero Ferrifero. Gold in quartz veins is found in Caraça group rocks associated with Precambrian banded iron-formations (BIF), and the BIF itself shows gold anomalies in the lateritic weathering profile. There are two types of quartz veins. The first type cut the itabirites and contain specularite but no gold. The second type are from the Batatal formation (Caraça group) and contain rare native gold particles. Systematic fluid inclusion studies using microthermometry and Raman spectrometry analyses have been carried out on different quartz veins crosscutting the Ouro Fino syncline series, in order to characterize the P-V-T-X conditions of the fluid circulation in the fault network.

2 . THE OURO FINO SYNCLINE : GEOLOGICAL SETTING AND WEATHERING OF THE BIF

The Ouro Fino syncline is a small perched syncline, in which refolding has resulted in an acute axial flexure (Fig. 1). The Caraça and Itabira groups (lower and middle units of the Minas Supergroup) form the skeletal structure of the Serra do Ouro Fino (Table 1). The lower unit (Caraça group) consists of Moeda and Batatal formations.The middle unit (Itabira group) is represented by the Caue formation. These formations are the only units preserved in the syncline. The Moeda formation is composed largely of a clean white fine-grained quartzite and minor amounts of sericitic phyllite (Maxwell, 1972). The Batatal formation is a homogeneous dark-gray graphitic argillite (Maxwell, 1972). The Caue formation (lower Itabira group) is composed of itabirites (or BIF), bedded metasedimentary rocks with alternating hematite/magnetite and quartz layers.

The itabirites are deeply weathered (down to as much as 200 m) and the different weathering horizons (Table 2) have been studied in detail (Ramanaidou, 1989). The first weathering stages (Soft Itabirite, SI and Hematite B, HB) are isovolumetric ; their desilicification is progressive but important, and geothitisation is moderate. When desilicification is almost complete in the Hematite A horizon (HA), the primary oxides (hematite and magnetite) are destabilized. An epigenetic replacement of the preexisting minerals occurs in

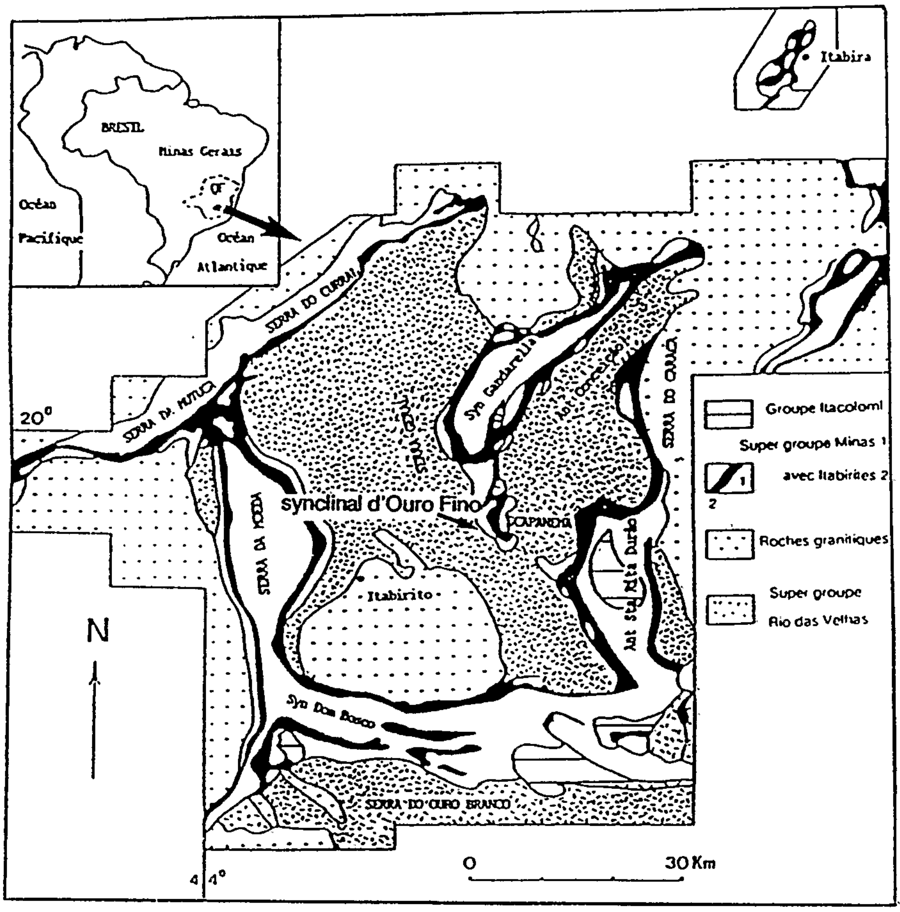

Fig. 1 :Location of the Quadrilatero ferriffero (Dorr, 1969)

Table 1. Simplified stratigraphy of the quadrilatero ferrifero (Ladeira, 1980).

Supergroup	Group	Formation
1350 Ma Minas	III and IV Itacolomi Sabara Piracicaba	
Minas	Itabira	Gandarella Caue
Minas 2000 Ma	Caraca	Batatal Moeda
Espinhaco 2675 Ma Rio Das Velhas Rio Das Velhas Rio Das Velhas	 Maquine Nova Lima Quebra Osso	

Table 2 : Weathering profiles on itabirites. (Ramanaidou, 1989)

SLOPES	Plateau (1)	Plateau (2)
Canga (C)	Canga	Canga
Hardened goethitic horizon (HGH)		
Hematite A (HA) Hematite B (HB)	HA HB	 HB
Soft itabirite (SI)	SI	SI
Itabirite (IT)	IT	IT

"clay-like red product" a
product consists of sma
hematite and goethite. Ir
horizon (HGH) the goethi
induration is strong lead
destruction of the primary
goethite-rich "cuirasse", tl
weathering column.
The plateau shows a rest
canga caps the HB or HA
are marked by a deep and
with a HGH horizon well

3 . GEOCHEMISTRY I PROFILE

3.1 . Raw data

Atomic absorption analysi
was used for the determina
3). Fresh itabirites d
concentrations which ran
laterites, the gold content
level as in the BIF but m
the bottom to the top of th
horizons. Near the surface
horizon, 30 to 40 ppb are
values are obtained in the
("clay-like red product") o

3..2 - Corrected data

Using the density of the
possible to compare the gc
of rocks in the different w
3). On the plateau, an en
the HB horizon and i
weathering effect is not v
leached. On the other h
profile, when HGH horiz
gold level seems erratic
compared to the bed rock
product, where the weath
gold is the lowest.
Thus, at the super
enrichments or depleti
weathering of the itabirit
gold loss or gain from on
however difficult to
concentrations (< 100 p
localization of the minerali
Though the gold in the E
values are anomalous, a
possible source of gold fc
veins.

4 . P-V-T-X CONDITIC FORMATION

Systematic fluid inclu
microthermometry and R

"clay-like red product" alumina rich pockets. This product consists of small particles of secondary hematite and goethite. In the Hardened Goethitic horizon (HGH) the goethitization is intense and the induration is strong leading sometimes to a total destruction of the primary bedding. A vesicular and goethite-rich "cuirasse", the so called canga caps the weathering column.

The plateau shows a restricted evolution where the canga caps the HB or HA horizons, while the slopes are marked by a deep and strong weathering column with a HGH horizon well developed.

3 . GEOCHEMISTRY IN THE WEATHERING PROFILE

3.1 . Raw data

Atomic absorption analysis (with a graphite furnace) was used for the determination of gold content (Table 3). Fresh itabirites display anomalous gold concentrations which range from 20 to 60 ppb. In laterites, the gold content remains at about the same level as in the BIF but may vary significantly from the bottom to the top of the hills, and in the different horizons. Near the surface (cuirasse) and in the HB horizon, 30 to 40 ppb are recorded, whereas lower values are obtained in the intermediate HA horizon ("clay-like red product") or in the HGH horizon.

3..2 - Corrected data

Using the density of the different samples, it is possible to compare the gold level for a same volume of rocks in the different weathering horizons (Table 3). On the plateau, an enrichment occurs mainly in the HB horizon and in the canga. When the weathering effect is not very strong, the gold is not leached. On the other hand, on very weathered profile, when HGH horizon is well developed, the gold level seems erratic and we observe a loss compared to the bed rock. In the pockets of the red product, where the weathering effect is the highest, gold is the lowest.

Thus, at the supergene stage, some gold enrichments or depletions could occur during weathering of the itabirites. The mechanisms of the gold loss or gain from one of the lateritic horizon is however difficult to solve since the low concentrations (< 100 ppb) make impossible any localization of the mineralogical form of gold.

Though the gold in the BIF is extremely low, these values are anomalous, and are considered to be a possible source of gold found in some of the quartz veins.

Table 3 : Variation in gold content (absolute and normalized at constant volume) in samples from the alteration profiles

Sample	Type	Au ppb	Density	ppb/100cm3
	Itabirites			
145	IT	4	3,27	13,08
CP07	IT	35	3,49	122,15
IT36	IT	68	3,1	210,8
123	IT	43	2,92	125,56
IT1	IT	20	2,79	55,8
CHBA300	IT	60	2,24	134,4
Profile 14 (upper slope)				
CHB91	SI	20	2,76	55,2
CHB92	SI	25	2,93	75,25
CHB93	HB	17	2,44	41,48
CHB94	HB	35	2,5	87,5
CC95	C	40	2,61	104,4
Profile 1 (upper slope)				
CHB6	HB	13	2,59	33,67
CHB10	HA	30	2	60
CHA14	HA	38	2,32	88,16
Profile 10 (slope)				
51	HA	45	2,06	92,7
52	HA	45	3,02	135,9
53	HA	20	2,17	43,4
55	HGH	35	3,08	107,8
56	HGH	25	2,4	60
57	HGH	33	3,13	103,29
CC58	C	32	2,57	82,24
Profile 4 (slope)				
131	HA	8	2,99	23,92
132	HA	39	1,92	74,88
133	HGH	10	2,41	24,1
134	HGH	11	2,96	32,56
135	HGH	28	1,49	41,72
136	HGH	16	2,95	47,2
137	HGH	11	2,9	31,9
138	HGH	14	3,71	37,94
139	C	10	2,12	21,2
Red products				
400	RP	6	1,7	10,2
103	RP	5	1,7	8,5

4 . P-V-T-X CONDITIONS OF QUARTZ VEIN FORMATION

Systematic fluid inclusion studies by using microthermometry and Raman spectrometry analysis have been carried out on different quartz veins crosscutting the Ouro Fino series, in order to characterize the P-V-T-X conditions of the fluid circulation in the fault network. Two vein types have been identified :

-type 1- barren quartz-specularite veins which are frequent in the Ouro Fino syncline. The studied quartz vein from the Capanema mine croscut the itabirite series and do not show any ductile deformation. They are centimetric to decimetric in width, are partly weathered near the surface. They do not show any gold concentration. Specularite crystallizes sometimes on cores of magnetite.

- type 2- quartz veins containing rare native gold particles, mostly located in metamorphic series surrounding the itabirites. Small and old scrapes attest of local investigations for gold. The weathering makes difficult the identification of the primary sulphide assemblages which are partially to totally transformed into iron oxydes and/ or hydroxydes.

Type 1 veins display three kind of inclusions. Most inclusions are scaterred within the quartz and no chronology could be established. No definite planes of fluid inclusions have been recognized. This suggest that most fluids are contemporaneous of the crystallization or recrystallization of the quartz.

a) two-fluid phase aqueous inclusions : the Tm H_2O are mostly in the -8.5;-10.5°C, whilst the temperature of first melting is low around -60°C. The Th (L-V)L range from 63 to 137°C.

b) sulfate rich inclusions

Two types are distinguished :

- hypersaline CO_2 -rich inclusions : they are multiphase and contain :

- one or more solids : a solid hexagonal in shape representing about 10% of the total volume of the inclusion, identified by Raman spectroscopy as a sulphate (barite, or celestite, ?). Other solids are difficult to identify. Tm of the hexagonal solid is around 140 ± 15 °C.

- a vapour phase dominated by CO_2 accompanied by small amounts of N_2. $ThCO_2$(L or V) is in the 1°-17.8°C range with a maximum between 7° and 14°C. Tm CO_2 in the -56.6° -56.8°C range indicate the presence of dominating CO_2 , which is confirmed by Raman spectroscopy ;

- a liquid phase where SO_4^{2-} is the dominant ion identified by Raman spectroscopy, while HSO_4^- ions are detected but in much lower concentrations. TmH_2O is in the -4.3°; -5.7°C range.

All studied inclusions decrepitated at temperatures ranging from 160 to 280°C

- bisulfate rich inclusions, are two-fluid phase inclusions characterized by the presence of an unidentified small solid. Most Tm H_2O ranges from -1.5 to -4.5 °C. Some TH (L-V)L are recorded around 230°C whilst most inclusions decrepitate at temperatures up to 290°C.

Considering the polyatomic species which can identified by Raman spectroscopy, the liquid phase contains both SO_4^{--} and HSO_4^- ions in rather similar concentrations.

Thanks to a calibration by using experimental solutions (Moissette et al., 1990), (SO_4^{--}) was estimated to be around 0.32 ± 0.05 molal, and pH around -0.3 ± 0.2 at 25°C in such inclusions. It is probably the first occurrence of such acid fluids in natural fluid inclusions.

-c) aqueous vapours : the vapour phase occupies around 80-90 % of the inclusion. No volatile species has been identified by Raman spectroscopy. No TH could be obtained due to decrepitation. The salinity of the vapours is estimated to be very low from the rare observation of ice melting near 0.0°C in some inclusions.

The fluid compositions, especially in type c inclusions are rather unusual : low pH at room temperature, sulfate rich aqueous solutions, some of them being mixed with volatiles (CO_2). The coexistence of aqueous vapours together with hypersaline fluids are probably indicative of boiling process which probably lead the crystallization of the quartz -hematite assemblage. The observed compositions reveal highly oxydizing conditions, and temperatures above 200-300°C. It is actually difficult to propose any source for such fluids (evaporites ?).

Type 2 quartz veins contain volatile rich fluids mostly borne by fluid inclusion trails. Each trail is characterized by rather homogeneous phase relationships at room temperature. Especially, the water filling which varies from nearly 0 up to 70% in the whole set of inclusions, is nearly constant within a given fluid inclusion plane. Textutal relationships suggest repeated fracturing, with the trapping of fluids characterized by increasing amounts of water.

Tm CO_2 ranges from -56.7 to 57.2°C with a maximum at -56.8°C. Tm H_2O when H_2O is present is in the -1.5 ; -11.5°C range with a maximum around -2.7°C. ThCO_2 (L-V)L shows rather constant values within a given trail, but varies greatly from trail to trail : it ranges from -11.5°C to + 29.8°C, with maxima at -7°C, +3°C, +17°C, and + 27°C. Most inclusions decrepitate at temperatures ranging from 180 to 320°C. Some global homogenization to the vapour phase have been obtained in the 320-400°C range. Raman spectroscopy reveals the presence of CH_4 , H_2S, (C_2H_6 and N_2) in the volatile phase. The presence of CH_4 reveals much lower fO_2 than for type 1 veins.

5 . CONDITIONS OF GOLD MOBILITY IN THE OURO FINO SERIES AT THE HYDROTHERMAL STAGE

Itabirites constitute the most probable source rocks for gold anomalies encountered in this area. At the hydrothermal stage, gold deposition seems to be restricted to the veins characterized by the presence of carbonic fluids (type2) characterized by rather low fO_2 and moderate pH, whilst no gold deposition characterizes the studied quartz-specularite veins which are characterized by high fO_2 (fO_2 greater than that fixed by the Hematite-magnetite buffer) and nearly neutral pH at 250°-300 °C.

Consideration of thermodynamical data on gold solubility gives a relatively good explanation to the different behaviour of gold in such contrasted conditions. Gold was probably easily transported in highly saline and oxydizing solutions and could not be deposited before any changes in the surrounding physical-chemical conditions (fO_2 or pH). Such changes could occur at the contact zones between itabirites and other metan
those characterized by spe
acting as buffers (graphite-
series from the Batatal grou

6 . CONCLUSIONS

This study has shown that :
- Itabirite which consis
magnetite or quartz layers l
content as a source rock.
levels (down to 200m) by
transforms the initial min
oxides and hydroxid
redistribution of gold ma
depletions (down to 5 p
However, the two successi
the itabirite, noted HB, HA
ferruginous cuirasse so-ca
contents have gold content
8-45 ppb range.
It is highly probable tha
lateritization is necessa
concentrations, such as f
reworking of the weathe
waters followed by a diff
gravity of the transporte
such process would nee
which were not carried ou
- the systematic fluid inc
by using microthermometr
analysis have shown th
compositions characterize
veins crocutting the Ouro
quartz-specularite veins (
kinds of fluids, with
compositions such as hyp
CO_2 rich fluid inclusion
conditions (T min.≈ 200-
(when recalculated at such
sulfate rich solutions)
incompatible with gold tra
On the contrary, the qu
native gold particles, most
series surrounding the itab
C-H-O-N-S rich fluids w
water. These fluids indica
and probable equilibrium
most fluids described in A
al., 1990, Alvarenga et al.

REFERENCES

Abreu S.F.A. 1973. Rec
2nd Ed., Vol. 2, Sao Pau
Alvarenga J.M. S, Cathe
1990.Chronology and
CO_2-H_2O and H_2O ric
intrametamorphic quartz
district, Brazil. Min. Ma
Boiron M.C., Cathelineau
A. 1990. Fluids in herc
french variscan belt. Mi

ıated to be very low from the
· melting near 0.0°C in some

tions, especially in type c
unusual : low pH at room
:h aqueous solutions, some of
vith volatiles (CO_2). The
ous vapours together with
robably indicative of boiling
· lead the crystallization of the
ssemblage. The observed
ighly oxydizing conditions,
ve 200-300°C. It is actually
any source for such fluids

contain volatile rich fluids
inclusion trails. Each trail is
ther homogeneous phase
temperature. Especially, the
es from nearly 0 up to 70% in
ons, is nearly constant within
plane. Textutal relationships
uring, with the trapping of
ncreasing amounts of water.
om -56.7 to 57.2°C with a
'm H_2O when H_2O is present
'C range with a maximum
L-V)L shows rather constant
rail, but varies greatly from
om -11.5°C to + 29.8°C, with
, +17°C, and + 27°C. Most
t temperatures ranging from
obal homogenization to the
ı obtained in the 320-400°C
opy reveals the presence of
l N_2) in the volatile phase.
veals much lower fO_2 than

GOLD MOBILITY IN THE
T THE HYDROTHERMAL

most probable source rocks
untered in this area. At the
ld deposition seems to be
aracterized by the presence
characterized by rather low
whilst no gold deposition
d quartz-specularite veins
by high fO_2 (fO_2 greater
natite-magnetite buffer) and
-300 °C.
nodynamical data on gold
ely good explanation to the
gold in such contrasted
bably easily transported in
ing solutions and could not
changes in the surrounding
itions (fO_2 or pH). Such
the contact zones between

itabirites and other metamorphic series, especially those characterized by specific mineral assemblages acting as buffers (graphite-sulphide rich metamorphic series from the Batatal group for instance).

6 . CONCLUSIONS

This study has shown that :

- Itabirite which consists of alterning hematite-magnetite or quartz layers have a relatively high gold content as a source rock. When affected in surficial levels (down to 200m) by a lateritic alteration, which transforms the initial mineralogy into complex iron oxides and hydroxide assemblages, some redistribution of gold may occur with some local depletions (down to 5 ppb in the red product). However, the two successive lateritic horizons above the itabirite, noted HB, HA,which are overlain by the ferruginous cuirasse so-called "canga"display gold contents have gold contents which remain within the 8-45 ppb range.

It is highly probable that further process than the lateritization is necessary to get higher grade concentrations, such as for instance a mechanical reworking of the weathered profiles by surficial waters followed by a differential sedimentation by gravity of the transported products. The study of such process would need specific investigations which were not carried out in our study.

- the systematic fluid inclusion studies carried out by using microthermometry and Raman spectrometry analysis have shown that rather different fluid compositions characterize the barren and mineralized veins crocutting the Ouro Fino series. The barren quartz-specularite veins (type 1) display different kinds of fluids, with, especially, unusual compositions such as hypersaline, sulfate rich and CO_2 rich fluid inclusions. The physical-chemical conditions (T min.≈ 200-300°C, pH nearly neutral (when recalculated at such temperatures, high fO_2, sulfate rich solutions) seem to have been incompatible with gold transport or deposition.

On the contrary, the quartz veins containing rare native gold particles, mostly located in metamorphic series surrounding the itabirites, are characterized by C-H-O-N-S rich fluids with varying amounts of water. These fluids indicative of relatively low fO_2, and probable equilibrium with graphite are similar to most fluids described in Au-quartz veins (Boiron et al., 1990, Alvarenga et al., 1990).

REFERENCES

Abreu S.F.A. 1973. Recursos minerais do Brasil, 2nd Ed., Vol. 2, Sao Paulo (E. Blucher).

Alvarenga J.M. S, Cathelineau M. & Dubessy J. 1990.Chronology and orientation of N2-CH4, CO2-H2O and H2O rich fluid inclusion trails in intrametamorphic quartz veins from the Cuiaba gold district, Brazil. Min. Mag. 54,245-255.

Boiron M.C., Cathelineau M., Dubessy J. & Bastoul A. 1990. Fluids in hercynian Au-veins from the french variscan belt. Min. Mag., 54,231-243..

Dorr J.V.N.II 1969. Physiographic, stratigraphic and structural development of the Quadrilatero Ferrifero, Minas Gerais, Brazil. U.S.G.S. Prof. Paper. 641A, 110 p.

Hoppe A., Schobbenhaus C & Detlef H.G.W. 1987. Precambrian Iron Formations in Brazil. Precambrian Iron Formations. Editors Peter. W. Uitterdijk Appel. Teophrastus Publications.

Ladeira E.A. 1980. Metallogenesis of gold at the Morro Velho mine and in Nova Lima district, Quadrilatero Ferrifero, Minas Gerais, Brazil. Univ. West Ontario. Unpubl. Ph. D. Thesis. 272 p.

Maxwell C.H. 1972. Geology and ore deposits of the Alegria district, Minas Gerais, Brazil. U.S.G.S. Prof. Paper. 341J. 72 p.

Moisette, A., Dubessy J, Cathelineau M., Ramanaïdou E. & Le Gleuher M. 1990 Fluids with high acidity evidenced by Raman micro-spectrometric analysis of sulfate and bisulfate ions in fluid inclusions from a gold showing (Brazil). IAGOD symposium. Ottawa (Canada). Abstract p.A18.

Ramanaidou E. 1989. Genese d'un gisement lateritique. Evolution supergene des itabirites Proterozoiques de la mine de fer de Capanema (Minas Gerais, Brazil). These Doct. Poitiers 183 p.

Siegers A. & Renger F. 1985. Gold mining in Brazil. Erzmetall., 38, 7/8, 351-358.

Ladeira, Eduardo A. (ed.) 90 6191 195 8
Brazil Gold '91– *The economics, geology, geochemistry and genesis of gold deposits – Proceedings of the symposium Brazil Gold '91, Belo Horizonte, MG, 13–17.05.1991*
1991, 25 cm, 844 pp., Hfl.165 / $95.00 / £50
Gold and gold deposits are one of the main focuses of pure and applied research in geological science at the present time. At the International Symposium *Brazil Gold '91*, participants from 23 countries and with a wide variety of research interests joined to present and discuss their latest contributions on the economics, geology, geochemistry and exploration of gold deposits.
The proceedings of *Brazil Gold '91* encompass 117 papers which are distributed in five sections: Regional studies; Petrology and geochemistry; Geology and case studie of gold deposits; Structural geology of gold deposits and districts; and Mineral exploration. They will be very useful for professional geologists, geophysicists and mining engineers concerned with precious metal deposits, whether working in research and development, industry, or mineral exploration. It will certainly also be an essential source for both undergraduate and graduate students in economic and applied geology.

RAMANAIDOU ERICK
N° 11

PROCEEDINGS OF THE SYMPOSIUM BRAZIL GOLD'91
BELO HORIZONTE / MG / 13 - 17 MAY 1991

BRAZIL GOLD '91

The Economics, Geology, Geochemistry and Genesis of Gold Deposits

Edited by

E.A. LADEIRA

Department of Geology, Institute of Geosciences, Universidade Federal de Minas Gerais, Belo Horizonte - MG

OFFPRINT

Published for the Associação Organizadora do Brazil Gold, Belo Horizonte, Brazil by

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1991