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HEAVY MINERALS IN THE SEDIMENTS FROM PARAGUAY RIVERS AS INDICATORS FOR DIAMONDS OCCURRENCES

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Abstract.- Indicator minerals are mineral species that, when appearing as transported grains in clastic sediments, indicate the presence in bedrock of a specific type of mineralization, hydrothermal alteration or lithology. Their physical and chemical characteristics, including a relatively high density (heavy minerals), facilitate their preservation and identification. The heavy minerals represent an important exploration method for detecting a variety of ore deposit types including diamond, gold, Ni–Cu, PGE, and so on. One of the most significant events in the application of indicator mineral methods in the past was the diamond exploration. After some works that quoted the presence of diamonds in Eastern Paraguay, we have performed a whole sampling study relative to the indicator mineral for diamonds. This paper provides an overview of indicator mineral methods, i.e. presence of Cr-diopside, Pyrope-rich garnet and Picroilmenite, for diamond exploration along the Eastern Paraguay rivers. Unfortunately the above heavy minerals, generally associated to the diamonds, do not appear in Eastern Paraguay, excluding this Country as a potential source for the diamond as economic potential source.

Keywords: *Heavy minerals*, *indicator minerals, diamonds, Eastern Paraguay.*

Resumen.- Los minerales indicadores son especies minerales que, cuando aparecen en forma de granos transportados en sedimentos clásticos, indican la presencia, en la roca madre, de un cierto tipo de mineralización, alteración hidrotermal o litología específicos. Sus características físicas y químicas, incluyendo una alta densidad relativa (minerales pesados), facilitan su preservación e identificación. La búsqueda de minerales pesados representa un importante método de exploración para detectar una variedad de tipos de depósitos en menas que incluyen diamantes, oro, Ni–Cu, PGE, etc. Uno de los eventos más significativos en la aplicación métodos con minerales indicadores en el pasado ha sido la exploración en busca de diamantes. Como consecuencia a varios trabajos mencionando la presencia de diamantes en Paraguay oriental, hemos ralizado un estudio de muestreo integral en busca de minerales indicadores de la presencia de diamantes. Este artículo proporciona un sumario de métodos usados para la búsqueda de diamantes en ríos de Paraguay oriental involucrando minerales indicadores, como la presencia de Cr-Diópsido, Picroilmenita y Granate rico en Piropo. Desafortunadamente los minerales mencionados, generalmente asociados con los diamantes, no aparecen en Paraguay oriental, excluyendo a este país de constituirse en un potencial proveedor de diamantes como fuente de ingresos económicos.

Keywords: *Heavy minerals*, *indicator minerals, diamonds, Eastern Paraguay.*

The dominant source rocks for diamonds are depleted peridotite (i.e. harzburgite and dunite) and high pressure eclogite). Kimberlites are the most important source for these gems; another possible primary source for diamonds are olivine lamproites. As matter of fact, it is apparent that kimberlites and lamproites are transporting agents carrying diamonds from its source region in the upper mantle to the crust (cf. Nowicki *et al*., 2007 and references therein). In addition to diamonds, the disaggregation of mantle rocks sampled by kimberlites and lamproites yields large quantities of other minerals, commonly referred to as kimberlite indicators, as Mg-garnet (pyrope), Cr-diopside, picroilmenite, chromite and olivine. From an exploration point of view, the most important indicators are the minerals that are the more chemically resistant, i.e. garnet, picroilmenite and chromite for their greater ability to survive weathering in the surface environment (e.g. river sediments).

Presser (2013, and references therein) and Presser *et al*. (2014), described the presence of lamproites and kimberlites and associated diamonds in various localities from Eastern Paraguay. Bitschene (1987) also cites K-rich mafic rocks with lamproitic affinities, although not specifically calling them true lamproites. On the other hand, Comin-Chiaramonti, Gomes and coworkers have not encountered kimberlitic-lamproitic rock types or diamonds after twenty years of field-geological-petrological-geophysical works in Eastern Paraguay (Comin-Chiaramonti and Gomes, 1996, 2005; Comin-Chiaramonti *et al*. 1989, 1999, 2013; Gomes *et al*., 2013 and therein references). About the definitions of "lamproite", "lamproitic rocks" and "lamproitic affinities" s. Le Maitre (1989) and therein references.

As matter of fact, this paper represents a systematic exploration over the sands from the rivers of Eastern Paraguay performed by Comin-Chiaramonti, Gomes and coworkers with the aim to determinate the presence of heavy minerals commonly associated to the diamonds.

Geological Background

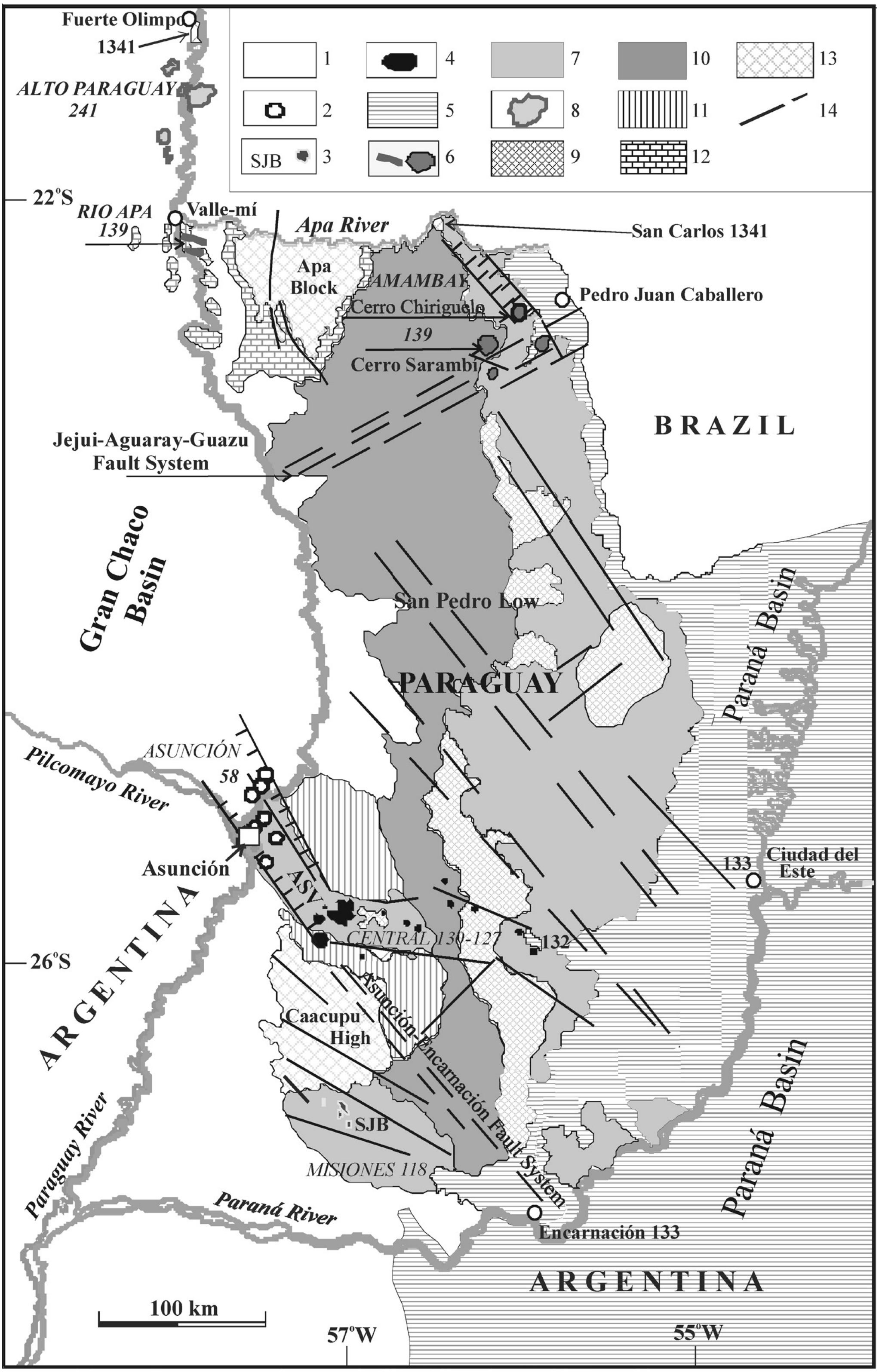
Eastern Paraguay lies in an intercratonic region which includes the westernmost side of the Brazilian Paraná Basin (PB). The latter represents an undeformed basin at the western Gondwana part with sedimentation beginning in the Ordovician, tapped by Early Cretaceous tholeiitic flood basalts of the Serra Geral Formation (Zalan *et al.*, 1990; Rogers *et al.*, 1995) and followed by younger sedimentation (Fig. 1).

PB is bounded at its western side by an anticlinal structure established since Early Paleozoic, the Asunción Arch separating the Paraná Basin (East) from the Gran Chaco (and Pantanal wetland) Basin (West) (Fig. 1; Almeida, 1983; Fulfaro, 1996; Comin-Chiaramonti *et al.*, 1997, 1999).

The two basins, from a geophysical point of view, have very different characteristics: PB shows a high-velocity upper-mantle lid with a maximum S-wave velocity of 4.7 km/s (Moho 37 km depth), with no resolvable low-velocity zone to at least a depth of 200 km; on the other hand, the distinguished feature of the Chaco Basin consists of a rather shallow Moho 30 km depth (Feng *et al.*, 2007), and low, asthenospheric, upper mantle S-wave velocities of about 4.2 km/s, with velocity increasing only slightly to about 4.3 km/s at about 150 km depth (Snoke & James, 1997).

The basement is represented mainly by Precambrian to Early Paleozoic (Bitschene & Lippolt, 1986) granitic intrusions and high to low-grade metasedimentary rocks (the northernmost occurrence of the Rio de La Plata craton and the southernmost tip of the Amazon craton according to Fulfaro, 1996; Comin-Chiaramonti *et al.*, 1997; Cordani *et al.*, 2001, 2005 and Mantovani *et al.*, 2005) at the southern and northern region of Eastern Paraguay (the Tebicuary block and the Apa block, respectively; cf. Fig. 1). Cordani *et al.* (2003a,b) suggested that the Tebicuary area represents a late Neoproterozoic mobile belt, North of the Rio de La Plata, whereas the Apa block corresponds to a Paleoproterozoic-Mesoproterozoic mass at the contact with the Paraguay mobile belt. Representative chemical analyses are in Petrini *et al*. (1987) and in Comin-Chiaramonti & Marques (1988).

Between the two blocks, Eastern Paraguay was subjected to NE-SW-trending crustal extension during Late Jurassic − Early Cretaceous probably related to the western Gondwana breakup (cf. Comin-Chiaramonti *et al.*, 1997, 1999, Cordani *et al*., 2000 and therein references). NW-SE fault trends, paralleling the dominant orientation of Mesozoic alkaline and tholeiitic dykes, reflect this type of structure (Druecker & Gay, 1987, Comin-Chiaramonti *et al.*, 1992a; Riccomini *et al.*, 2001). The resulting structural pattern controlled the development of grabens or semigrabens as a response to NE-SW-directed extension


Fuerte Olimpo
1341
ALTO PARAGUAY
241
1
2
SJB 3
4
5
6
7
8
9
10
11
12
13
14
22°S
RIO APA
139
Valle-mí
Apa River
San Carlos 1341
Apa Block
AMAMBAY
Cerro Chiriguelo
139
Cerro Sarambi
Pedro Juan Caballero
Jejui-Aguaray-Guazu Fault System
BRAZIL
Gran Chaco Basin
San Pedro Low
PARAGUAY
Paraná Basin
ASUNCIÓN
58
Pilcomayo River
Asunción
ASV
133
Ciudad del Este
CENTRAL 130-127
132
26°S
ARGENTINA
Caacupu High
Asunción-Encarnación Fault System
SJB
MISIONES 118
Paraguay River
Paraná River
Encarnación 133
Paraná Basin
ARGENTINA
100 km
57°W
55°W

and continued evolving into Cenozoic times (Comin-Chiaramonti & Gomes, 1996; Comin-Chiaramonti *et al.*, 1999). According to Tommasi and Vauchez (2001), rift orientations seem to have been controlled by the pre-existing lithospheric mantle fabric, as revealed by deep geophysical data.

The basement is represented mainly by Precambrian to Early Paleozoic granitic intrusions and high to low-grade metasedimentary rocks (the northernmost occurrence of the Rio de La Plata craton and the southernmost tip of the Amazon craton, according to Fúlfaro, 1996) at the southern and northern regions of Eastern Paraguay corresponding to the Tebicuary block and the Rio Apa block, respectively (Fig. 1). Cordani *et al.* (2003a,b) suggested that the Tebicuary area represents a late Neoproterozoic mobile belt, at north of the Rio de La Plata, whereas the Rio Apa block constitutes a Paleoproterozoic-Mesoproterozoic mass in contact with the Paraguay mobile belt.

Between the two blocks, Eastern Paraguay was subjected to NE-SW-trending crustal extension during Late Jurassic-Early Cretaceous probably related to the western Gondwana breakup (Comin-Chiaramonti *et al.*, 1997, 1999). NW-SE fault trends, paralleling the dominant orientation of Mesozoic alkaline and tholeiitic dykes, reflect this type of structure (Comin-Chiaramonti *et al.*, 1992; Riccomini *et al.*, 2001). The resulting structural pattern controlled the development of grabens or semigrabens as a response to NE-SW-directed extension and continued evolving into Cenozoic times (Comin-Chiaramonti and Gomes, 1996; Comin-Chiaramonti *et al.*, 1999). According to Tommasi and Vauchez (2001), rift orientations seem to have been controlled by the pre-existing lithospheric mantle fabric, as revealed by deep geophysical data.

Six main magmatic events occurred (Fig. 1) from the end of the Paleozoic to the Cenozoic. This is shown by geological evidence and by previous regional and geochronological studies (Bitschene & Lippolt, 1986, Bitschene, 1987 and references therein) as follows (cf. also Comin-Chiaramonti & Gomes, 1996, 2005 and references therein):

1) Permo-Triassic sodic magmatism of the Alto Paraguay Province (255 -210 Ma; Gomes *et al*., 1996 and references therein) is widespread on the southernmost side of the Amazon Craton (Fulfaro, 1996; Comin-Chiaramonti *et al*., 2005a).

2) Potassic alkaline-carbonatitic complexes and dykes from North Eastern Paraguay, from the Rio Apa (~142 Ma, as inferred from Gibson *et al*., 1995) and Amambay areas (avg. 141 Ma; Sonoki & Garda, 1988; Eby & Mariano, 1992) predate the tholeiitic flood basalts (Paraná, Serra Geral Formation, SGF).

3) The Paraná SGF flood tholeiites and dykes (133 ± 1 Ma according to Renne *et al*., 1992, 1993, 1996; 137-127 Ma, according to Bitschene, 1987, Turner *et al*., 1994 and Stewart *et al*., 1996) are both represented by high-Ti and low-Ti basalts (cf. Bellieni *et al*., 1986, Bitschene, 1987, Piccirillo & Melfi, 1988).

Opposite page: Figure 1. Geological sketch map showing the alkaline magmatism distribution in Paraguay (after Comin-Chiaramonti *et al.* 1997, 1999 and unpublished geological maps). 1.Quaternary sedimentary cover; 2. Tertiary alkaline rocks (Asunción Province); 3.Late Early Cretaceous alkaline rocks (Misiones Province, San Juan Bautista); 4. Early Cretaceous alkaline rocks (post-tholeiites, Central Province); 5.Early Cretaceous tholeiites in the Paraná Basin; 6. Early Cretaceous alkaline rocks (pre-tholeiites, Apa and Amambay Provinces); 7.Jurassic-Cretaceous sedimentary rocks (Misiones Formation); 8.Permo-Triassic alkaline rocks (Alto Paraguay Province); 9. Permian sedimentary rocks (Independencia Group); 10. Permo-Carboniferous sedimentary rocks (Coronel Oviedo Group); 11. Ordovician-Silurian sedimentary rocks (Caacupé and Itacurubí Groups); 12. Cambro-Ordovician platform carbonates (Itacupumí Group); 13.Archean and Neoproterozoic crystalline basement; 14.Major tectonic lineaments and faults.

4) Potassic alkaline complexes and dykes (132-115 Ma; Bitschene, 1987; Comin-Chiaramonti & Gomes, 1996) with subordinate silico-carbonatite flows and dykes are widespread mainly in the Asunción-Sapucai-Villarrica graben (ASU, central potassic province; Comin-Chiaramonti *et al*., 1997; 1999).

5) Sodic alkaline complexes, plugs and dykes (~120 Ma; Comin-Chiaramonti *et al*., 1992), occur mainly at the Misiones Province (San Juan Bautista Region), southwestern Paraguay.

6) Paleogene sodic alkaline complexes, plugs and dykes (66-33 Ma; Bitschene, 1987; Comin- Chiaramonti *et al*., 1991; Comin-Chiaramonti & Gomes, 1996) crop out on the western side of the Asunción-Sapucai-Villarrica graben.

The Permo-Triassic rocks form subcircular complexes following a N-S trend and are mainly formed by nepheline syenites and syenites and their effusive equivalents (Comin-Chiaramonti *et al*., 2005). Early Cretaceous alkaline magmatism, both pre-dating and post-dating the tholeiitic effusions, is moderately to strongly potassic, being represented by rock types spanning from alkali basalt to trachyte and from basanite to phonolite and their intrusive equivalents. They are often associated with carbonatitic rock types (Bitschene, 1987, Comin-Chiaramonti & Gomes, 1996; Comin- Chiaramonti *et al*., 1997; 1999). Early Cretaceous tholeiites are mainly basalts and andesibasalts, both belonging to the high-Ti and the low-Ti suites (Bellieni *et al*., 1986, Bitschene, 1987, Piccirillo & Melfi, 1988; Comin-Chiaramonti & Gomes, 1996; Peate *et al*., 1999).

The Cretaceous and Paleogene sodic rocks, including ankaratrites, nephelinite and phonolites, are both characterized by mantle xenoliths (spinel peridotite facies; Bitschene, 1987; Bitschene & Presser, 1992; Comin-Chiaramonti *et al*., 1992; 2001 and references therein).

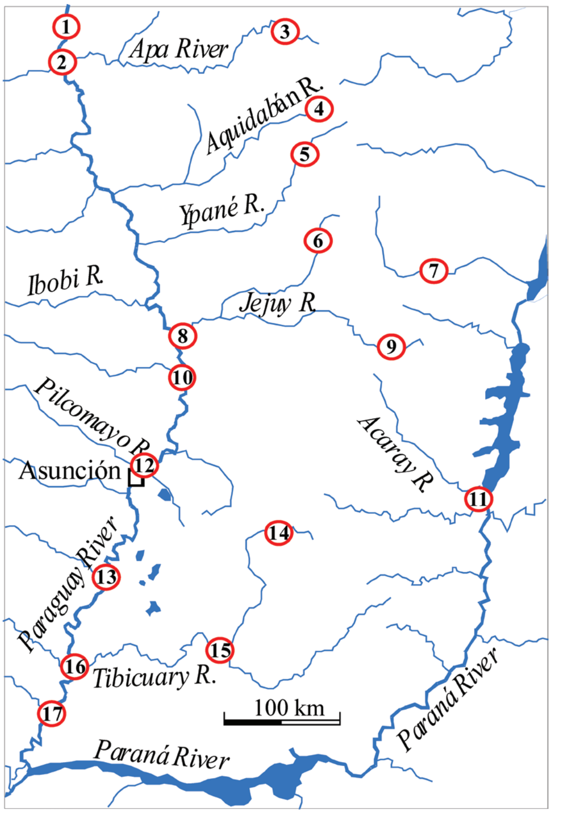


Figure 2. Eastern Paraguay rivers with the sites (1 to 17) sampled for the separation of heavy minerals. Note that the indicated localities roughly correspond to those indicated by Presser (2008, 2013) as diamondiferous.

The thermal history, using apatite fission track analyses (AFTA), reveals that at least two main episodes have been identified in sedimentary and igneous/metamorphic samples ranging in age from Late Ordovician to Early Cretaceous (Hegarty *et al*., 1996). AFTA data from Asunción-Sapucai-Villarrica graben (ASU) show evidence for rapid cooling beginning sometime between 90 and 80 Ma, similar to the results from Brazilian and Uruguayan coasts; a Ce heating/cooling episode is also revealed by AFTA, supporting early work in the area. The time of the first event is significantly younger than any rifting activity related to the Paraná flood basalts and the opening of the South Atlantic. Late

Cretaceous cooling may have involved several kilometers of differential uplift and erosion, and would have played an important role on the control of the geomorphology and drainage patterns in the region (cf. Fig. 1), especially in the Asunción-Sapucai-Villarrica graben system

Table 1. Heavy minerals (wt%) occurring in the 1-17 localities of Fig. 2. The mineral types are described in order of abundance.

	Wt %	Heavy Minerals
1	9	Clinopyroxene (aegirine); Amphibole (pargasite); Biotite; Magnetite; Ilmenite; Titanite; Apatite; Zircon, Pyrite
2	16	Clinopyroxene (diopside); Olivine; Perovskite: Magnetite; Ilmenite; Biotite; Apatite:; Zircon
3	18	Clinopyroxenes (diopside, aegirine-augite); Olivine; Amphibole (hastingsite); Biotite; Garnet (andradite);b Ilmenite; Pyrite: Apatite: Zircon: Biotite; Perovskite
4	23	Clinopyroxenes (augite, aegirine); Garnet (andradite); Phlogopite; Magnetite; Ilmenite; Apatite; Titanite; Zircon; Perovskite.
5	21	Clinopyroxene (diopside); Olivine; Magnetite; Ilmenite; Biotite; Apatite; Zircon
6	24	Clinopyroxene s (augite, pigeonite); Magnetite; Ilmenite: Biotite; Apatite; Zircon
7	19	Clinopyroxenes (augite, orthopyroxene); Magnetite; Ilmenite: Biotite; Apatite; Zircon
8	17	Clinopyroxenes (diopside); Amphibole (hornblende); Magnetite; Ilmenite: Biotite; Apatite; Zircon
9	23	Clinopyroxene (augite, pigeonite); Magnetite; Olivine; Ilmenite: Apatite; Zircon
10	22	Clinopyroxene (diopside); Amphibole (hornblende); Magnetite; Ilmenite, Apatite; Zircon
11	17	Clinopyroxene s (augite, pigeonite); Olivine; Magnetite; Calcopyrite; Copper; Ilmenite; Apatite; Zircon
12	35	Olivine; Clinopyroxene (diopside); Orthopyroxene ; Spinel; Magnetite; Ilmenite; Apatite; Zircon
13	8	Clinopyroxene (diopside); Olivine; Manetite; Ilmenite; Zircon
14	15	Clinopyroxene (diopside); Olivine; Magnetite; Ilmenite; Biotite; Amphibole (magnesio katophorite); Titanite; Apatite; Zircon
15	25	Olivine; Clinopyroxene (diopside); Orthopyroxene (enstatite); Spinel; Phlogopite; Ilmenite; Magnetite; Apatite; Zircon
16	14	Clinopyroxene (diopside, augite); Orthopyroxene (enstatite) ; Olivine; Magnetite; Ilmenite; Spinel: Amphibole (Hornblende); Apatite; Zircon
17	12	Clinopyroxene (diopside, augite); Amphibole (hornnlende); Manetite; Ilmenite; Apatite; Zircon; Titanite, Pyrite

(see below).

On the basis of Druecker and Gay's (1987) interpretation for some NW-trending aeromagnetic anomalies detected in the Eastern Paraguay, some authors suggest that the anomalies (*e.g.* Peate, 1997; Gibson *et al.*, 2006) represent a giant tholeiitic dyke swarm, similar to the Brazilian Ponta Grossa dyke swarm (Piccirillo *et al.*, 1990), mainly located in the northwestern part of the area, in particular north of the Asunción-Sapucai-Villarrica graben (ASVG). Also, the geologic sketches of Bitschene (1987, p. 272) suggest NW-trending tholeiitic dykes. We have intensively worked in the country since 1982 and up to now we did not find any field evidence of the dyke swarm, as suggested by Drueker and Gay (1987). Thus, it is quite possible that most magnetic anomalies correspond indeed to Precambrian tectonic lineaments, as shown by Comin-Chiaramonti *et al.* (1999). On the contrary, in ASU more than 200 alkaline dykes were sampled and mapped (Comin-Chiaramonti, 1992, 1996a, b, c).

Sampling

Indicator minerals are mineral species that, when appearing as transported grains in clastic sediments, indicate the presence in bedrock of a specific type of mineralization, hydrothermal alteration or lithology. Their physical and chemical characteristics, including a relatively high density, facilitate their preservation and identification and allow them to be readily recovered from sample media such as till, stream sediments or soil producing large exploration targets (Ottensen and Theobald, 1994; McClenaghan, 2005).

Most commonly, if the topography is suitable, stream sediments are the best sample medium. The preferred procedure is to wet-sieve the sample by carefully shoveling the sediments into a -20 mesh stainless steel sieve (diameter 36 cm, depth 17 cm) resting in a large aluminum pan containing water.

Using handles on the sieve, a washing-machine type motion is used to sieve the sediments. In this manner approximately 10 kg of 20 mesh material is collected. Care must be taken to clean the sieves and pans to prevent contamination. Heavy mineral concentrates are best produced through the application of heavy liquid separation. First, the samples are wet sieved into several fractions, dried, and further sieved if necessary. A chosen size fraction(s) is then slowly fed into the middle of a column of tetrabromethene (TBE), specific gravity 2.96. The resultant heavy minerals are then further separated by methylene iodide (MI), specific gravity 3.27. The specific gravity of the heavy liquid can be lowered to ensure that particular minerals are in a unique fraction. For example, in diamond exploration, a liquid with a specific gravity of 3.2 can be used, to include chrome diopside. A Frantz electromagnetic separator is then used to generate distinct fractions based on variations in magnetic susceptibility (usually magnetic, para-magnetic and non-magnetic fractions). In the case of diamond indicator prospecting, four fractions are generated, separating most regional garnets from kimberlitic pyropes. Electrodynamic separation can be utilized to concentrate picro-ilmenite from nonmetallic gangue.

Heavy mineral techniques should not be used to the exclusion of other geochemical methods. The case histories, which are described below, demonstrate the importance of combining complementary methods, especially during the follow-up of anomalies. It is also crucial to carry out orientation field and lab studies before processing the samples. Decisions need to be made as to which size, specific gravity and magnetic susceptibility fractions to produce. For example in diamond exploration, a magnetic separation that can distinguish between regional metamorphic garnets and pyrope garnets would be most useful. Generally one chooses a fraction that casts as broad a mineralogical/geochemical

Table 2. Microrobe analyses of selected heavy minerals (wt%), as in Table 1. The mineral types are described in order of abundance. Compositions were obtained at the "Istituto di Geoscienze e Georisorse, CNR, Padova", by wavelenght dispersion method at different accelerating voltages and beam currentsb (15-20 kV abd 10-20 nA, respecively: cf. Carbonin et al., 2005).

1	Aegirine-Augite	Pargasite	Biotite	Magnetite	Ilmenite	Titanite	**2**	Diopside	Olivine	Magnetite	Ilmenite	Perovskite	
SiO_2	52.09	48.68	35.68	0.19	0.05	30.50	SiO_2	50.74	33.04	0.29	0.26	TiO_2	55.91
TiO_2	0.85	1.51	4.60	9.94	50.73	38.65	TiO_2	0.62	0.02	23.57	47.86	Al_2O_3	0.06
Al_2O_3	0.65	1.47	12.29	0.08	0.07	0.23	Al_2O_3	2.83	0.04	1.54	0.15	FeO_t	1.25
Cr_2O_3	0.08	0.05	0.11	0.06	0.01	-	Cr_2O_3	0.12	0.01	0.14	0.12	CaO	37.36
Fe_2O_3	25.33	3.16	11.34	48.80	2.75	-	Fe_2O_3	0.86	0.11	20.85	8.90	Na_2O	1.53
FeO	4.85	27.22	20.02	38.25	34.24	0.35(*)	FeO	10.82	44.31	52.29	40.72	La_2O_3	0.60
MnO	1.35	1.48	0.83	1.93	11.24	0.06	MnO	0.56	0.87	0.88	0.57	Ce_2O_3	1.27
MgO	0.63	2.54	5.22	0.02	0.02	-	MgO	15.37	21.41	0.26	0.62	Pr_2O_3	0.18
CaO	3.12	4.31	0.01	0.08	0.02	27.41	CaO	18.09	0.20	0.02	-	Nd_2O_3	0.22
Na_2O	10.79	5.56	0.50	-	-	0.29	Na_2O	0.08	-	-	-	Nb_2O_5	0.24
K_2O	0.10	1.26	8.93	-	-	0.01	K_2O	0.01	-	-	-	SrO	0.38
Sum	99.84	98.32	99.53	99.35	99.13	97.50	Sum	100.10	99.99	99.84	99.20	Sum	99.00

3	Diopside	Aegirine-Augite	Olivine	Hastingsite	Andradite	Ilmenite	Magnetite	**4**	Augite	Aegirine-	Andradite	Phlogopite	Ilmenite
SiO_2	49.80	59,28	33.32	42.50	36.48	0.04	0.17	SiO_2	50.11	52.91	35.38	41.18	0.02
TiO_2	1.69	0.25	0.04	0.95	0.49	50.37	7.30	TiO_2	1.80	3.22	0.10	0.04	51.80
Al_2O_3	5.24	0.23	0.06	8.59	6.78	0.03	2.72	Al_2O_3	2.89	1.54	0.12	10.57	0.05
Cr_2O_3	0.13	0.03	0.05	0.03	9,93	0.05	0.80	Cr_2O_3	0.03	0.05	0.05	0.65	0.08
Fe_2O_3	-	-	-	-	21.94	5.29	49.22	Fe_2O_3	3.48	16.87	31.58	4.55	5.67
FeO	27.19(*)	28.57(*)	48.04(*)	21.11(*)	3.29	40.32	37.29	FeO	6.23	11.07	0.37	3.80	39.10
MnO	0.08	1.35	1.67	0.55	0.60	4.91	0.17	MnO	0.32	0.18	0.22	0.05	2.08
MgO	14.04	0.52	16.48	7.52	0.10	0.03	0.29	MgO	11.74	0.63	0.21	24.86	0.89
CaO	22.01	11.78	0.38	11.11	30.12	-	0.01	CaO	22.98	2.40	31.24	0.21	0.07
Na_2O	0.42	5.86	-	2.10	-	-	-	Na_2O	0.79	10.95	0.03	0.56	-
K_2O	0.01	0.01	-	1.50	-	-	-	K_2O	0.03	0.11	-	9.96	-
Sum	100.71	98.88	100.09	95.99	99,94	101.04	97.97	Sum	100.40	99.93	99.30	96.54	99.76

Table 2 (continued). Microrobe analyses of selected heavy minerals (wt%), as in Table 1. The mineral types are described in order of abundance. Compositions were obtained at the "Istituto di Geoscienze e Georisorse, CNR, Padova", by wavelenght dispersion method at different accelerating voltages and beam currentsb (15-20 kV abd 10-20 nA, respecively: cf. Carbonin et al., 2005).

5	Diopside	Olivine	Magnetite	Ilmenite	Biotite	**6**	Augite	Pigeonite	Magnetite	Ilmenite	Biotite	Apatite
SiO_2	53.24	34.42	0.95	0.23	34.80	SiO_2	48.21	52.84	0.51	0.35	35.24	-
TiO_2	1.24	0.11	3.40	53.20	3.37	TiO_2	2.36	0.22	5.39	51.81	3.86	-
Al_2O_3	1.56	0.21	13.47	0.57	18.63	Al_2O_3	6.38	0.44	8.10	0.42	15.46	0-04
Cr_2O_3	0.08	0.04	0.01	0.04	0.08	Cr_2O_3	0.84	0.02	0.42	0.06	0.09	-
Fe_2O_3	2.25	1.51	46.45	0.55	2.48	Fe_2O_3	-	1.06	47.84	4.08	6.91	0.10
FeO	2.67	41.96	30.46	38.10	19.04	FeO	5.95(*)	16.89	33.88	39.78	19.53	0.04
MnO	0.15	0.63	0.15	0.44	0.41	MnO	0.09	0.56	0.14	0.22	0.60	0.11
MgO	16.37	21.17	4.70	5.26	7.82	MgO	13.79	23.51	2.50.	4.00	6.55	-
CaO	20.90	0.30	-	-	1.25	CaO	22.74	4.06	-	-	0.63	53.89
Na_2O	0.31	-	-	-	0.20	Na_2O	0.44	0.19	-	-	0.39	P_2O_5: 41.00
K_2O	0.01	-	-	-	8.58	K_2O	-	-	-	-	8.76	REE: 1.79
Sum	98.96	100.35	99.89	98.39	96.66	Sum	100.80	99.79	98.78	100.72	98.02	96.9'

7	Augite	Orthopy.	Magnetite	Ilmenite	Biotite	**8**	Hornbl.	**9**	Augite	Pigeonite.	Olivine	Magnetite	Ilmenite
SiO_2	51.19	53.17	0.23	0.27	33.11	SiO_2	44.53	SiO_2	49.68	55.27	37.67	0.35	0.33
TiO_2	1.33	0.22	20.87	50.36	1.79	TiO_2	0.91	TiO_2	1.85	0.05	-	23.62	50.16
Al_2O_3	1.77	0.45	1.61	0.05	15.58	Al_2O_3	10.15	Al_2O_3	4.03	0.62	-	1.71	0.41
Cr_2O_3	0.14	0.08	0.36	0.05	0.02	Cr_2O_3	0.23	Cr_2O_3	0.51	1.13	-	0.02	0.01
Fe_2O_3	2.27	1.32	27.34	2.22	-	Fe_2O_3	6.10	Fe_2O_3	3.13	-	-	21.38	4.62
FeO	9.51	17.18	50.42	43.77	21.20(*)	FeO	11.31	FeO	7.71	9.62(*)	26.78(*)	51.91	42.59
MnO	0.31	0.48	0.14	1.09	0.43	MnO	0.33	MnO	0.19	0.43	0.29	0.90	0.13
MgO	14.62	23.81	0.36	0.41	9.60	MgO	10.40	MgO	14.20	28.80	35.05	0.31	1.56
CaO	17.39	2.47	-	-	0.02	CaO	11.59	CaO	20.02	3.23	0.25	0.09	-
Na_2O	0.07	0.27	-	-	0.19	Na_2O	1.48	Na_2O	0.22	0.41	-	-	-
K_2O	-	-	-	-	6.52	K_2O	1.21	K_2O	-	-	-	-	-
Sum	99.99	99.45	100.72	98.22	88.46	Sum	98.24	Sum	101.54	99.56	100.04	100.31	99.81

Table 2 (continued). Microrobe analyses of selected heavy minerals (wt%), as in Table 1. The mineral types are described in order of abundance. Compositions were obtained at the "Istituto di Geoscienze e Georisorse, CNR, Padova", by wavelenght dispersion method at different accelerating voltages and beam currentsb (15-20 kV abd 10-20 nA, respecively: cf. Carbonin et al., 2005).

10	Diopside	Hornb,	Apatite	Titanite	Ilmenite	**11**	Augite	Pigeonite	Olivine	Magnetite	Ilmenite	**12**	Olivine
SiO_2	54.61	40.94	0.31	30.79	0.22	SiO_2	51.52	56.37	36.64	0.33	0.23	SiO_2	41.23
TiO_2	0.23	2.69	0.02	37.94	45.92	TiO_2	0.33	0.11	0.25	25.90	50.80	TiO_2	-
Al_2O_3	1.30	13.28	0.09	1.91	0.02	Al_2O_3	6.65	0.71	0.19	3.41	0.98	Al_2O_3	-
Cr_2O_3	0.32	0.46	-	-	0.38	Cr_2O_3	0.82	1.11	0.22	0.04	0.02	Cr_2O_3	-
Fe_2O_3	0.79	3.14	-	-	12.40	Fe_2O_3	0.67	-	2.81	14.30	2.65	Fe_2O_3	-
FeO	3.33	13.14	0.36	1.76(*)	38.11	FeO	3.00	8.43 (*)	23.66	52.35	41.95	FeO	9.30 (*)
MnO	0.10	0.27	0.04	0.05	0.60	MnO	0.14	0.51	1.01	0.45	0.25	MnO	0.15
MgO	20.88	10.01	-	0.20	1,59	MgO	15.88	29.74	31.26	1.95	2.09	MgO	49.94
CaO	16.20	10.37	54.38	27.12	-	CaO	19.50	3.28	3.37	-	-	CaO	0.03
Na_2O	1.28	3.12	0.10	0.03	-	Na_2O	1.36	0.09	0.18	-	-	Na_2O	-
K_2O	0.12	1.04	P_2O_5 42.00	-	-	K_2O	-	0,02	-	-	-	K_2O	-
Sum	99.06	98.46	97.30	99.61	99.24	Sum	99.87	100.50	99.59	98.80	98.97	Sum	100.65

12	Orthopy.	Diopside	Spinel	**13**	Diopside	Olivine	Magnetite	Ilmenite	**14**	Diopside	Olivine	Magnetite	Ilmenite
SiO_2	56.86	55.25	-	SiO_2	54.91	41.11	0.25	0.23	SiO_2	52.68	37.00	0.77	0.87
TiO_2	0.07	0.29	0.06	TiO_2	0.24	0.02	22.34	50.01	TiO_2	1.23	-	16.08	52.71
Al_2O_3	3.33	5.61	56.53	Al_2O_3	3.40	0.03	1.45	0.11	Al_2O_3	1.73	-	0.42	0.07
Cr_2O_3	0.24	0.23	12.38	Cr_2O_3	0.71	0.07	0.01	0.07	Cr_2O_3	0.15	0.06	0.80	0.14
Fe_2O_3	-	-	-	Fe_2O_3	1.10	0.40	24.06	6.38	Fe_2O_3	0.55	0.53	38.10	2.91
FeO	5.77 (*)	2.43 (*)	10.63 (*)	FeO	1.88	10.86	50.32	42.87	FeO	5.75	28.99	56.44	36.51
MnO	0.13	0.10	0.11	MnO	0.12	0.18	1.64	0.52	MnO	0.16	1.19	1.12	1.29
MgO	33.77	15.40	20.70	MgO	18.14	48.18	0.36	1.03	MgO	16.36	32.61	1.65	4.52
CaO	0.49	21.13	-	CaO	18.61	0.12	-	-	CaO	21.85	0.18	0.07	-
Na_2O	0.05	1.52	-	Na_2O	1.44	-	-	-	Na_2O	0.30	-	-	-
K_2O	-	-	-	K_2O	-	-	-	-	K_2O	-	-	-	-
Sum	100.71	100.16	100.41	Sum	100.55	100.97	100.43	101.22	Sum	100.66	100.56	99.88	99.02

Table 2 (continued). Microrobe analyses of selected heavy minerals (wt%), as in Table 1. The mineral types are described in order of abundance. Compositions were obtained at the "Istituto di Geoscienze e Georisorse, CNR, Padova", by wavelenght dispersion method at different accelerating voltages and beam currentsb (15-20 kV abd 10-20 nA, respecively: cf. Carbonin et al., 2005).

14	Biotite	Magnesio Katophorite	Titanite	Apatite
SiO_2	38.93	51.67	30.15	0.79
TiO_2	9.48	4.45	38.25	0.04
Al_2O_3	10.83	2.31	1.17	0.76
Cr_2O_3	0.06	-	--	-
Fe_2O_3		-	--	-
FeO	12.99(*)	10.12(*)	1.34(*)	0.61(*)
MnO	0.12	0.15	0.05	0.03
MgO	15.06	15.72	0.04	0.01
CaO	-	5.05	27.40	53.40
Na_2O	0.35	6.29	0.07	0.15
K_2O	9.96	2.24	-	P_2O_5 42.00
Sum	97.78	98.00	98.52	97.79

15	Olivine	Diopside	Enstatite	Spinel	Phlogopite	Ilmenite
SiO_2	41.61	53.40	56.82	0.15	43.96	0.05
TiO_2	0.03	0.39	0.09	0.19	0.60	40.58
Al_2O_3	0.07	6.48	3.32	49.14	14.81	0.26
Cr_2O_3	0.02	0.22	0.43	17.48	0.08	0.03
Fe_2O_3	-	-	-	-	-	22.90
FeO	8.26(*)	2.24(*)	5.87(*)	11.14(*)	3.31(*)	31.71
MnO	0.20	0.16	0.11	0.13	0.10	0.41
MgO	49.81	14.95	34.17	20.37	26.73	2.47
CaO	0.10	19.98	0.49	0.01	-	0.02
Na_2O	-	1.87	0.08	-	0.51	-
K_2O	-	-	-	-	10.08	-
Sum	100.10	99.70	100.37	99.03	100.18	98.43

16	Diopside	Augite	Enstatite	Olivine	Biotite	Spinel
SiO_2	56.41	48.86	55.79	36.20	36.98	0.10
TiO_2	0.31	1.43	0.04	0.09	5.31	1.37
Al_2O_3	2.51	9.27	5.56	0.21	13.47	58.13
Cr_2O_3	0.23	0.01	-	0.02	0.11	0.03
Fe_2O_3	1.05	2.27	-	1.09	2.18	0.43
FeO	4.29)	4.87	2.25	23.19	9.98	22.07
MnO	0.37	0.15	0.02	0.33	0.19	0.10
MgO	20.71	14.22	35.81	36.86	16.67	14.50
CaO	13.89	18.59	0.07	0.04	0.06	-
Na_2O	-	1.08	-	-	0.25	-
K_2O	-	-	-	-	11.12	-
Sum	99.77	100.75	99.54	98.03	96.32	96.73

17	Diopside	Magnetite	Ilmenite	Titanite
SiO_2	52.53	0.46	0.12	30.08
TiO_2	0.72	21.05	44.29	36.94
Al_2O_3	1.64	2.65	0.19	1.70
Cr_2O_3	0.36	0.23	0.03	-
Fe_2O_3	0.57	31.00	16.50	0.92
FeO	3.18	41.98	37.69	0.99
MnO	0.06	0.63	0.57	0.11
MgO	15.71	1.56	0.57	0.03
CaO	24.26	0.15	0.17	28.06
Na_2O	0.25	-	-	-
K_2O	-	-	-	-
Sum	99.18	99.70	100.13	98.83

net as possible, without significantly diluting the target elements or minerals. However, in some circumstances more than one fraction is required for each sample (cf. Nowicki et al., 2007, and therein references).

For this purpose 17 sites were sampled along the banks of the rivers from Eastern Paraguay (Fig. 2), and sand fractions (5 to 0.05 mm) were separated by sieve in situ. The heavy minerals were separated utilizing the previous described methods (cf. also Basford and Coscio, 1973 and Rosenblum, 1958; King, 2001, and therein references). The results relative to the heavy mineral fractions (minerals with density >2.9 g/cc) are reported in Table 2.

CONCLUSIONS

From tables 1 and 2 it is apparent that heavy minerals commonly associated to diamonds in kimberlites and lamproites, i.e. Cr-diopside ($Cr_2O_3 \geq 1.45$ wt%; cf. Morris *et al*., 2002), pyrope (MgO between 19 and 25%) and picroilmenite (Mg rich ilmenite, i.e. between 8 and 10 MgO wt.%), i.e. the major typomorphic minerals widely used in geological prospecting (cf. Erlich and Dan Hausel, 2002), are absent in the sampled sands from Eastern. Moreover, in the same country, rock-types belonging to the kimberlitic-lamproiitic clans also were not encountered (over 600 chemical analyses of whole rocks: cf. Piccirillo & Melfi, 1988; Comin-Chiaramonti & Gomes, 1996, 2005).

As matter of fact, in Eastern Paraguay the diopside show Cr_2O_3 range between 0.08 and 0.36 wt%, MgO in ilmenite is 0.02-5.29% and garnet, when present, is andradite. Notably the latter chemical composition are contrasting even considering the APIP heavy minerals (cf. Fernandes *et al*., 2014).

Notably, we did not find diamonds nor a heavy mineral paragenesis indicative of diamond-bearing host rocks. Therefore, our findings do not support the findings of Presser *et al*. (2014), although we cannot exclude the occurrence of primary diamonds in Paraguay.

Concluding, the estimated diamond contents in the regions from Eastern Paraguay are considered to be very low, or absent and therefore without economic interest.

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