positive association was observed among the disease indices (Table 4), suggesting that any of the four disease indices are useful for accurate measurement of sheath rot disease and identification of resistant genotypes.

In the present study, new proposed disease indices were more accurate in measurement of disease resistance and identification of resistant genotypes compared to existing disease index. *In vitro* based detached lesion and panicle discolouration indices were relatively more variable due to the turgidity and genotypic variation for nodal roots developed during incubation period. Therefore, severity and lesion indices derived from the mean values of disease incidence and severity parameters were more accurate in differentiating resistant-susceptible genotypes and useful in crop improvement breeding for disease resistance in rice.

1. Chen, M. J., Studies in sheath rot of rice. *J. Agric. Forestry Taiwan*, 1957, **7**, 84–102.
2. Amin, K. S., Sharma, B. D. and Das, C. R., Occurrence of sheath rot of rice in India caused by *Acrocylindrium*. *Plant Dis. Rep*., 1974, **58**, 358–360.
3. Chakravarthy, D. K. and Biswas, S., Estimation of yield loss in rice affected by sheath rot. *Trans Br. Mycol. Soc*., 1978, **62**, 226–227.
4. Raina, G. L. and Singh, G., Sheath rot outbreak in Punjab. *Int. Rice Res. Newsl.,* 1980, **5**(1), 16.
5. Milagrosa, S., Transmission of *Sarocladium oryzae* (Sawada) W. Gams & Hawksv through rice seeds. Ph D thesis, University of the Philippines, Los Banos, Philippines, 1987.
6. Shakthivelu, N. and Gnanamanickam, S. S., Isolation of and assay of cerulenin produced by rice sheath rot pathogen *Sarocladium oryzae* (Swada). *Curr. Sci*., 1986, **55**(19), 988–989.
7. Tschen, L. C., Shean-Tzong, H. and Wu, T. W., Isolation and phytotoxic effects of helvolic acid from plant pathogenic fungus *Sarocladium oryzae*. *Bot. Bull. Acad. Sin.*, 1997, **38**, 251–256.
8. Ghosh, M. K., Amudha, R., Jayachandran, S. and Sakthivel, N., Detection and quantification of phytotoxic metabolites of *Sarocladium oryzae* in sheath rot-infected grains of rice. *Lett. Appl. Microbiol*., 2002, **34**, 398–401.
9. Nandakumar, R., Babu, S., Amutha, G., Raguchander, T. and Samiyappan, R., Variation in toxin production among isolates of *Sarocladium oryzae*, the rice sheath rot pathogen. *Plant Path. J*., 2007, **6**, 120–126.
10. Hittalmani, H., Mahesh, H. B., Mahadevaiah, C. and Prasannakumar, M. K., *De novo* genome assembly and annotation of rice sheath rot fungus *Sarocladium oryzae* reveals genes involved in helvolic acid and cerulenin biosynthesis pathways. *BMC Genomics*, 2016, **17**, 271; doi:10.1186/s12864-016-2599-0.
11. Gopalakrishnan, C., Kamalakannan, A. and Valluvaparidasan, V., Effect of seed-borne *Sarocladium oryzae*, the incident of rice sheath rot on rice seed quality. *J. Plant Protect. Res*., 2010, **50**(1), 98–102.
12. Lakshmanan, P., Mohankumar, S. and Velusamy, R., Role of *earhead bug* (*Leptocorisa acuta*) feeding on *sheath rot disease caused by Sarocladium oryzae in rice* (*Oryza sativa L.*) *in India. Phytoparasitica*, 1992, **20**(2), 107–112.
13. Reddy, M. M., Reddy, C. S. and Reddy, A. G. R., Influence of season and planting date on sheath rot incidence ID rice. *Indian Phytopathol*., 1999, **52**(3), 289–290.
14. Reddy, M. M., Reddy, C. S. and Reddy, A. G. R., Influence of weather parameters and insect pest populations on incidence and development of sheath rot of rice. *Indian Phytopathol.*, 2001, **54**(2), 179–184.
15. IRRI, Standard evaluation system for rice, Rice Knowledge Bank, 2002; www.knowledgebank.irri.org
16. Narayanasamy, P. and Viswanathan, R., A new scoring system for sheath rot of rice. *Madras Agric. J*., 1990, **77**(5–6), 256–257.
17. Madhav, M. S., Latha, G. S., Padmakumari, A. P., Somasheakar, N., Mangruthia, M. N. and Viraktamath, B. C., Phenotyping rice for molecular plant breeding. In *Phenotyping for Plant Breeding: Applications of Phenotyping Methods for Crop Improvement* (eds Kumar, P. S. and Kumar A. A.), Springer, 2013, pp. 15–16.
18. Samiyappan, R. *et al*., Purification and partial characterization of a phytotoxin produced by *Sarocladium oryzae*, the rice sheath rot pathogen. *Arch. Phytopathol. Plant Protect*., 2003, **36**, 247–256.
19. Mahadevaiah, C., Shailaja, H., Uday, G. and Prasanna Kumar, M. K., Standardization of disease screening protocol for sheath rot disease in rice. *Int. J. Agric. Sci. Res*., 2015, **5**(5), 129–135.
20. Srinivasachary, Shailaja, H., Girish Kumar, K., Shashidhar, H. E. and Vaishali, M. G., Identification of quantitative trait loci associated with sheath rot resistance (*Sarocladium oryzae*) and panicle exsertion in rice (*Oryza sativa* L.). *Curr. Sci.*, 2002, **82**(2), 133–135.
21. Hittalmaini, S., Girishkumar, S. K., Bagali, P. G., Srinivasachary and Shashidar, H. E., Identification of QTLs associated with sheath rot resistance in two mapping populations of rice (*Oryza sativa* L.). In Fourth International Rice Genetics Symposium, Los Banos. *Rice Genetic Newsletter*, 2000, vol. 16, pp. 87–88.

Received 8 July 2015; revised accepted 10 August 2016

doi: 10.18520/cs/v112/i01/151-155

Manganilmenite in the magnetite ore body from Pokphur area of Nagaland, North East India and the possibility of microdiamonds in the ophiolites of Indo-Myanmar ranges

Bibhuranjan Nayak[1,3]* and Franz Michael Meyer[2]

[1]Mineral Processing Division, CSIR-National Metallurgical Laboratory, Jamshedpur 831 007, India
[2]Institute for Mineralogy and Economic Geology, RWTH Aachen University, D-52056 Aachen, Germany and German-Mongolian Institute of Resource Technology (GMIT), 2nd Khoro, Nalaikh District, Ulaanbaatar, Mongolia
[3]Present address: CSIR-Institute of Minerals and Materials Technology, Bhubaneswar 751 013, India

Manganilmenite is found to be associated with the magnetite ore body of Pokphur area in the Nagaland ophiolites, North East India. There is perhaps no earlier description of the mineral from the Indian subcontinent. It occurs as an accessory mineral with magnetite and Fe-chlorite (chamosite). Electron probe micro-analytical data reveal that the mineral contains 5.6–8.5 wt% MnO and traces of MgO, ZnO and Cr_2O_3, while the TiO_2 content remains within narrow limits of 50–53 wt%. The calculated pyrophanite

*For correspondence. (e-mail: brn69@rediffmail.com)

end-member varies from 13% to 18%. Although the magnetite body of Pokphur has been reasonably proved to be a hydrothermally altered product of basic and ultrabasic igneous rocks, and most of the minerals in the magnetite body are supergene in nature, different end-member compositions of mangan–ilmenite indicate that it has originally crystallized with the basic suite of rocks and has survived the alteration process with only marginal effects. Since manganilmenite has been considered as a diamond indicator mineral and ophiolites are a newly documented host of microdiamonds elsewhere in the world, the presence of manganilmenite in the Pokphur magnetite hints towards occurrence of microdiamonds in the ophiolite suite of rocks of the Indo-Myanmar ranges.

Keywords: Diamond indicator mineral, ophiolite, magnetite ore body, manganilmenite.

MANGANESE-bearing ilmenite was first described from Western Australia that contained about 14.4 wt% MnO (ref. 1), and was accepted by the American Mineralogical Society as a new mineral with the name manganilmenite[2]. In the literature, analogous minerals are known as manganoan ilmenite, mangan-ilmenite or Mn-ilmenite. Since basically the mineral is an ilmenite with considerable manganese content, we prefer to use the term 'manganilmenite' in accordance with the first description of this mineral. Although relatively rare, manganilmenite occurs as an accessory mineral in magmatic and metasomatic rocks, and has been reported from many localities. It has been described from ferrogabbro in the Skaergaard intrusion, Greenland[3] in adamellite from California[4], Leinster granite, Ireland[5] the agpaitic and hyperagpaitic pegmatites in the Lovozero and Khibiny complexes of Kola peninsula, Russia[6,7], in regionally metamorphosed mafic and ultramafic rocks from Archean greenstone belts of Western Australia[8]; Kola Peninsula, Russia[9], in peralkaline syenites at Pilansberg, South Africa and Pocos de Caldas, Brazil[10,11]; kimberlitic pipes of Pandrea, Brazil and Guanaimo, Venezuela[12,13]. Most of the literature deals with its origin and summarily manganilmenite formed at the latest magmatic or postmagmatic, metasomatic stages and manganilmenite inclusions in diamonds are primary-magmatic. The importance of manganilmenite has been increasing in exploration as a diamond indicator mineral since Tompkins and Haggerty[14], and Kaminsky *et al.*[15] recommended that it be included in the list of diamond indicator minerals. To our knowledge, manganilmenite has not been reported from the Indian sub-continent until the present authors indicated its presence in the recent past[16]. In this communication, we describe the characters of manganilmenite from the Pokphur magnetite body that occurs in the northeastern most part of the Nagaland–Manipur ophiolite belt, a part of the Indo-Myanmar ranges in North East India, and discuss its origin and the significance of its occurrence in such ophiolitic rocks.

In the Pokphur area, the magnetite body occurs as discontinuous thin sheets extending about a kilometre in strike length over a cumulate sequence of meta-ultramafics. The thickness of the body varies from 5 to 12 m with an average outcrop width of about 300 m. The underlying rocks of the cumulate complex consist of dunite, harzburgite, lherzolite, olivine–pyroxenite, pyroxenite, and amphibolite containing various proportions of olivine, orthopyroxene, clinopyroxene, amphibole, biotite, epidote, and plagioclase. The low-temperature hydrothermal reactions between iron-silicates and water that releases excess iron during serpentinization/chloritization have formed the magnetite body[16]. Hydrogen released by this reaction acts as the reducing agent. An exemplary reaction could be

$$\underset{\text{(Olivine)}}{6Fe_2SiO_4} + 7H_2O = \underset{\text{(Serpentine)}}{3Fe_3Si_2O_5(OH)_4} + \underset{\text{(Magnetite)}}{Fe_3O_4} + H_2. \quad (1)$$

Five samples from the magnetite body of Pokphur area were investigated using a Leica optical petrological microscope under reflected light. Quantitative microchemical compositions of the mineral phases were determined by an electron probe micro-analyser (EPMA; JEOL Superprobe JXA-8900R having five WDX and one EDAX spectrometers) using WDX and suitable standards with a focused beam of 1.6 μm diameter and accelerated voltage of 25 kV. The relative percentage error was less than 1 in all cases. Measurements were taken for 10 s with background time of 5 s, and probe current was kept at 27 nA. Quantitative volume fractions of various mineral phases were determined using an FEI QEMSCAN 650F with two EDAX attachments (Bruker 133 eV). Measurements were taken using a 5-μm grid with 2000 counts/s at an accelerated voltage of 25 kV.

Optical microscopic studies reveal that the samples collected from the magnetite body consist of magnetite and lesser amounts of chromite that are dispersed in a matrix of Fe-chlorite (chamosite). Quantified mineral modal abundance by QEMSCAN indicated that these three minerals constitute about 95 vol% of the samples (62.2 vol% chamosite, 30.6 vol% magnetite and 1.9 vol% chromite averaging five samples). In three samples manganilmenite was recorded (0.01–0.11 vol%). In these samples, manganilmenite occurs as isolated elongated crystals or in clusters of few grains associated with Fe-chlorite and magnetite (Figure 1). When found within chlorite mass, the grain boundaries are smooth and the crystals are almost intact, whereas when associated with magnetite the grain boundaries are corroded in general and it is evident that magnetite replaces manganilmenite in the grain boundaries. The grains vary in size from less than 50 to more than 200 μm. Under reflected plane-polarized light, manganilmenite has a greyish-brown colour with dominantly brownish shade (more brown compared to magnetite). It has low reflectivity (lower than

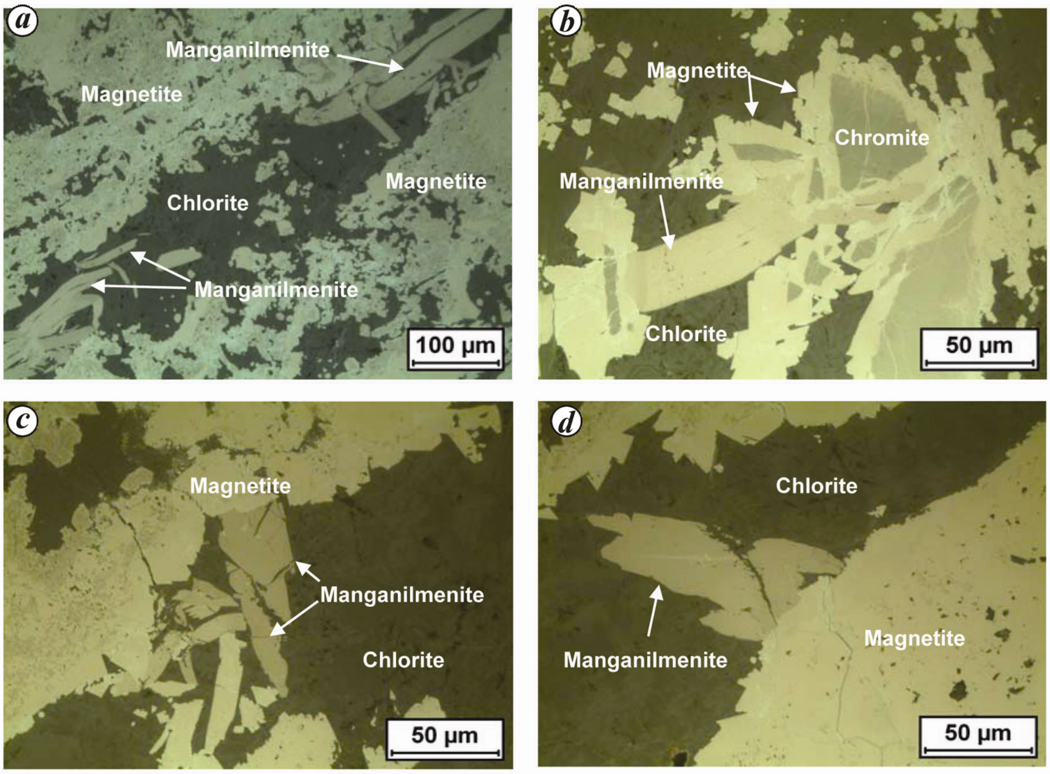

Figure 1. Modes of occurrence of manganilmenite in the magnetite body of Pokphur, Nagaland, NE India. ***a***, Elongated unaltered crystals of manganilmenite with smooth grain boundaries found within Fe-chlorite. ***b***, Manganilmenite associated with magnetite is fractured and marginally replaced by magnetite. ***c***, ***d***, Relatively smooth grain boundaries of manganilmenite with Fe-chlorite, and blunt and corroded boundary with magnetite.

magnetite) and is distinctly pleochroic. High anisotropism under crossed polars is characteristic of this mineral.

Mineral chemical composition determined by EPMA reveals that manganilmenite contains 5.6–8.5 wt% MnO and traces of MgO, ZnO and Cr_2O_3, while the TiO_2 content remains within narrow limits of 50–53 wt% (Table 1). Calculated Fe_2O_3 content does not exceed 4 wt%. Analyses on different points on the same grain are found to be almost identical and did not show any indication of zoning in the mineral. End-member compositions of manganilmenite were calculated on the basis of two cations which revealed variation of pyrophanite end-member from 13% to 18%, while ilmenite end-member remained between 81% and 87%. While eskolaite and geikielte were negligible, hematite varied from ~0.5% to over 4.5%. When the end-member compositions were plotted in the Quaternary system $FeTiO_3$–$MnTiO_3$–$MgTiO_3$–Fe_2O_3, manganilmenite was found to be affiliated to the basic suite of rocks[17,18] (Figure 2).

Ilmenite crystallizes in the trigonal crystal system and has a rhombohedrally centred lattice where solid solutions exist among ilmenite ($FeTiO_3$), geikielite ($MgTiO_3$) and pyrophanite ($MnTiO_3$)[19]. While magnesian ilmenite commonly occurs in kimberlites, manganoan ilmenite is characteristic of alkaline rocks, carbonatites and granites[6]. The concentrations of manganese in ilmenite can be explained by two hypotheses[5]. First, ilmenite could crystallize from melts that are enriched in Mn relative to Fe (ref. 20). The second hypothesis is that oxidation reactions during or after crystallization can account for the Mn enrichment in ilmenite[4]. For example, while the primary ilmenite in the Tibchi granite, northern Nigeria is slightly enriched in Mn, the secondary ilmenite found along fractures and fissures has much increased Mn content that could be attributed to the hydrothermal transfer of Mn along fissures in later stages[21]. In general, primary ilmenite has a uniform chemical composition and the supergene ones show variable compositions from core to rim. Experimental results too indicate that primary ilmenites are homogeneous grains[19]. The petrographic characteristics and mineral chemistry (homogeneous composition) of manganilmenite in the study area, therefore, suggest that it is magmatic in origin and is a primary mineral.

Manganilmenite is not a standard diamond indicator mineral. However, Tompkins and Haggerty[14], and Kaminsky *et al.*[15] recommended that it be included in the list of diamond indicator minerals. This is because low-magnesian ilmenite (with only 0.11–0.14 wt% MgO) was first reported as an inclusion in three ‘Brazilian’

Table 1. Chemical composition of manganilmenite (wt% by EPMA) in the magnetite ore body of Pokphur, Nagaland, NE India and its calculated structure on the basis of two cations

Probe/sample no.	2/1 rim	2/2 core	2/3 rim	2/29 rim	2/30 core	2/31 rim
SiO_2	0.02	0.01	0.35	0.04	0.01	0.00
P_2O_5	0.00	0.01	0.02	0.00	0.00	0.00
Al_2O_3	0.03	0.01	0.26	0.01	0.00	0.00
Cr_2O_3	0.04	0.03	0.10	0.05	0.21	0.02
TiO_2	50.40	51.69	50.04	50.97	52.25	52.68
CaO	0.00	0.00	0.02	0.00	0.00	0.00
MgO	0.04	0.01	0.00	0.01	0.00	0.00
MnO	6.13	6.28	6.10	6.71	5.62	8.53
ZnO	0.03	0.03	0.04	0.03	0.02	0.00
FeO (*t*)	42.61	41.01	42.32	41.72	42.32	39.29
FeO (*c*)	39.04	40.10	38.82	39.02	41.29	38.74
Fe_2O_3 (*c*)	3.96	1.01	3.89	3.00	1.14	0.62
Total	99.69	99.18	99.64	99.84	100.54	100.59
On the basis of two cations						
Si	0.0005	0.0003	0.0088	0.0010	0.0003	0.0000
P	0.0000	0.0002	0.0005	0.0000	0.0000	0.0000
Al	0.0009	0.0003	0.0078	0.0003	0.0000	0.0000
Cr	0.0008	0.0006	0.0020	0.0010	0.0042	0.0004
Ti	0.9608	0.9893	0.9527	0.9700	0.9868	0.9939
Ca	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000
Mg	0.0015	0.0005	0.0000	0.0005	0.0000	0.0000
Mn	0.1316	0.1353	0.1308	0.1438	0.1195	0.1812
Zn	0.0006	0.0006	0.0007	0.0006	0.0003	0.0000
Fe (*t*)	0.9033	0.8729	0.8959	0.8828	0.8889	0.8243
Fe^{2+} (*c*)	0.8277	0.8535	0.8219	0.8257	0.8673	0.8127
Fe^{3+} (*c*)	0.0756	0.0194	0.0740	0.0571	0.0216	0.0116
End-member composition (%)						
Eskolaite	0.04	0.03	0.10	0.05	0.21	0.02
Geikielite	0.15	0.05	0.00	0.05	0.00	0.00
Pyrophanite	13.16	13.53	13.08	14.38	11.95	18.12
Ilmenite	82.77	85.35	82.19	82.57	86.73	81.27
Hematite	3.88	1.04	4.63	2.95	1.11	0.59

FeO(*t*), As determined by EPMA; (*c*), Calculated values.

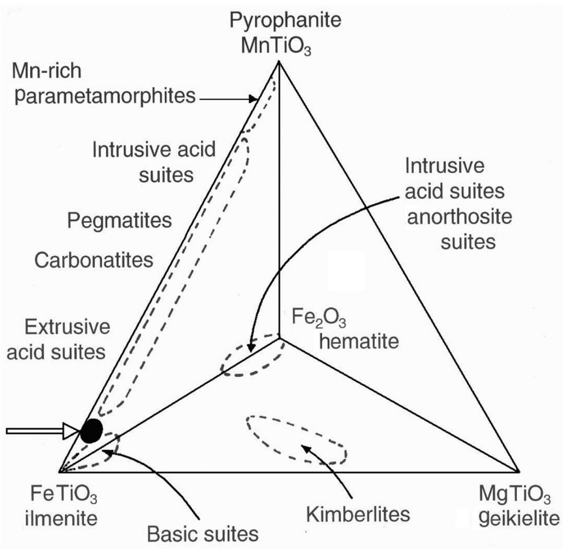

Figure 2. Generalized distribution of rhombohedral phases in the Quaternary system $FeTiO_3$–$MnTiO_3$–$MgTiO_3$–Fe_2O_3 (after Haggerty[17]; modified after Nayak and Mohapatra[18]). The compositions of manganilmenite from Pokphur (black circular area) show affinity towards basic suite rocks.

diamonds by Meyer and Svisero[22], who noted that it has a stoichiometric composition with major impurity of manganese (MnO: 0.64–0.75 wt%). McCallum[23] noted relative abundance of Mn-ilmenite at several widely separated and mostly diamondiferous kimberlite localities, which supports its value in exploration. Kaminsky *et al.*[15] too found a series of low-Mg manganoan ilmenite inclusions in Juina placer diamonds in which the MnO content varies from 0.42 to 2.12 wt%; in two grains MnO reaches 6.01 and even 11.46 wt%. MgO content in all these grains is very low (<0.81 wt%). Inclusions of low-Mg, Mn-ilmenite were found in placer diamonds from Guaniamo, Venezuela[24–26]. Also, the manganilmenites found in tills across Lena West both in and outside the Cretaceous basin are similar to those in the kimberlites from Guanaimo[27]. Recently manganilmenite has been found as an inclusion in a diamond from a primary deposit kimberlitic pipe-Pandrea-7 in the Juina area of Brazil[13]. Hence low-Mg manganilmenite is gaining importance as a diamond indicator mineral in recent times. The value of manganilmenite as a kimberlite/diamond indicator mineral may be of particular practical importance in the areas where the usual kimberlitic minerals (such as pyrope garnet and chrome-diopside) are not present, either because of the low concentration of kimberlites or because they could not survive the tropical environment such as in South America, India and Australia[12].

Now the questions – 'does the association of manganilmenite in the magnetite body of Pokphur indicate any occurrence of diamonds in the area or not?', and 'do the ophiolitic rocks of Indo-Myanmar ranges host diamonds or not?' needs to be discussed.

Over the last three decades, there have been a number of reports of diamonds in ophiolitic peridotites[28], but these findings have generally been doubted as anthropogenic or natural contaminations. However, ophiolites are a newly documented host of diamonds on the Earth, and abundant diamonds have been separated from peridotites and chromitites of ophiolites in China, Myanmar and Russia[29]. Diamond grains have been recently discovered in chromitite from the Cretaceous Luobusa ophiolite, Tibet[30], in ophiolitic massifs along the Yarlung–Tsangpo suture zone[31] from the early Paleozoic Ray–Iz ophiolite, polar Urals, Russia; in podiform chromitites of the Devonian Sartohai ophiolite in western China, and in peridotites of the Jurassic Myitkyina ophiolite, Myanmar[29]. These ophiolitic diamonds occur as subhedral to euhedral crystals, ~0.2–0.5 mm in diameter. These microdiamonds are accompanied by a wide range of highly reduced minerals, such as Ni–Mn–Co alloys, Fe–Si and Fe–C phases, and moissanite (SiC)[32,33]. They have been found as either mineral separates or inclusions in diamonds and indicate growth under super-reducing conditions. Since ophiolites are fragments of ancient oceanic lithosphere emplaced onto continental margins, accretionary prisms, or island arcs during plate collisions[34], the diamond-bearing chromite grains likely formed near the mantle transition zone and were then brought to shallow levels in the upper mantle to form podiform chromitites in oceanic lithosphere[29].

The Nagaland–Manipur ophiolite suite is a part of the Indo-Myanmar ranges. Since the geologic conditions of formation of these rocks are similar to those of the ophiolites of Luobusa (Tibet) and Myitkyina (Myanmar), the possibility of occurrence of microdiamonds in these rocks cannot be ruled out. Moreover, the present authors have provided evidence that the magnetite body of Pokphur has formed due to low-temperature hydrothermal alteration of basic and ultrabasic rocks in extremely reducing conditions, where metallic alloys such as Cu–Fe, Cu–Fe–Co, and Fe–Ni have formed in the magnetite body[16]. Therefore, all these circumstantial evidences, viz. (1) favourable geological situation, (2) occurrence of low-Mg manganilmenite, and (3) highly reducing environment with metallic alloys, suggest that the ophiolitic rocks of Indo-Myanmar ranges could host microdiamonds. A deliberate search in this direction might provide interesting results and would reveal the conditions of formation of such mantle rocks.

1. Simpson, E. S., Contributions to the mineralogy of Western Australia. *J. R. Soc. West Austr.*, 1929, **15**, 99–113.
2. Foshag, W. F., New mineral names: manganilmenite. *Am. Mineral.*, 1935, **20**, 403.
3. Vincent, E. A. and Phillips, R., Iron–titanium oxide minerals in layered gabbros of the Skaergaard intrusion, East Greenland. *Geochim. Cosmochim. Acta*, 1954, **6**(1), 1–34.
4. Snetsinger, K. G., Manganoan ilmenite from a Sierran adamellite. *Am. Mineral.*, 1969, **54**(4), 431–435.
5. Elsdon, R., Manganoan ilmenite from the Leinster granite, Ireland. *Mineral. Mag.*, 1975, **40**, 419–421.
6. Mitchell, R. H., Manganoan magnesian ilmenite and titanian clinohumite from the Jacupiranga carbonatite, Sao Paulo, Brazil. *Am. Mineral.*, 1978, **63**(5–6), 544–547.
7. Mitchell, R. H., *Kimberlites: Mineralogy, Geochemistry, and Petrology*, Plenum Press, New York, 1986.
8. Cassidy, K. F., Groves, D. I. and Binns, R. A., Manganoan ilmenite formed during regional metamorphism of Archean mafic and ultramafic rocks from Western Australia. *Can. Mineral.*, 1998, **26**(4), 999–1012.
9. Khomyakov, A. P., *Mineralogy of Hyperagpaitic Alkaline Rocks (in Russian)*, Nauka, Moscow, 1990.
10. Mitchell, R. H. and Liferovich, R. P., Ecandrewsite–zincian pyrophanite from lujavrite, Pilansberg alkaline complex, South Africa. *Can. Mineral.*, 2004, **42**(4), 1169–1178.
11. Mitchell, R. H. and Liferovich, R. P., The pyrophanite–ecandrewsite solid solution: crystal structures of the $Mn_{1-x}Zn_xTiO_3$ series $(0.1 \leq x \leq 0.8)$. *Can. Mineral.*, 2004, **42**(6), 1871–1880.
12. Kaminsky, F. V. and Belousova, E. A., Manganoan ilmenite as kimberlite/diamond indicator mineral. *Russ. Geol. Geophys.*, 2009, **50**, 1212–1220.
13. Kaminsky, F. V., Khachatryan, G. K., Andreazza, P., Araujo, D. and Griffin, W. L., Super-deep diamonds from kimberlites in the Juina area, Mato Grosso State, Brazil. *Lithos*, 2009, **112**, 833–842.
14. Tompkins, L. A. and Haggerty, S. E., Groundmass oxide minerals in the Koidu kimberlite dikes, Sierra Leone, West Africa. *Contrib. Mineral. Petrol.*, 1985, **91**(3), 245–263.
15. Kaminsky, F. V., Zakharchenko, O. D., Davies, R., Griffin, W. L., Khachatryan-Blinova, G. K. and Shiryaev, A. A., Superdeep diamonds from the Juina area, Mato Grosso State, Brazil. *Contrib. Mineral. Petrol.*, 2001, **140**(6), 734–753.
16. Nayak, B. and Meyer, F. M., Tetrataenite in terrestrial rock. *Am. Mineral.*, 2015, **100**, 209–214.
17. Haggerty, S. E., Opaque mineral oxides in terrestrial igneous rocks. *Rev. Mineral.*, 1976, **3**, Hg101–Hg300.
18. Nayak, B. R. and Mohapatra, B. K., Two morphologies of pyrophanite in Mn-rich assemblages, Gangpur Group, India. *Mineral. Mag.*, 1998, **62**(6), 847–856.
19. Feenstra, A. and Peters, T., Experimental determination of activities in $FeTiO_3$–$MnTiO_3$ ilmenite solid solution by redox reversals. *Contrib. Mineral. Petrol.*, 1996, **126**, 109–120.
20. Czamanske, G. K. and Mihálik, P., Oxidation during magmatic differentiation, Finnmarka complex, Oslo Area, Norway: Part 1, the opaque oxides. *J. Petrol.*, 1972, **13**(3), 493–509.
21. Sakoma, E. M. and Martin, R. F., Oxidation-induced postmagmatic modifications of primary ilmenite, NYG-related aplite dyke, Tibchi complex, Kalato, Nigeria. *Mineral. Mag.*, 2002, **66**, 591–604.
22. Meyer, H. O. A. and Svisero, D. P., Mineral inclusions in Brazilian diamonds. *Phys. Chem. Earth*, 1975, **9**, 785–795.
23. McCallum, M. E., Oxide minerals in Chicken Park kimberlite, Northern Colorado. In *Kimberlites and Related Rocks, II* (ed. Ross), 4th International Kim. Conference, 1989, pp. 759–770.
24. Kaminsky, F. V., Zakharchenko, O. D., Channer, D. M. D., Blinova, G. K. and Bulanova, G. P., Diamonds from the Guaniamo area, Bolivar state, Venezuela. In Memorias del VIII Congreso

Geologico Venezolana. Soc. Venezolana de Geol., 1997, pp. 427–430.
25. Kaminsky, F. V., Zakharchenko, O. D., Griffin, W. L., Channer, D. M. and Khachatryan-Blinova, G. K., Diamond from the Guaniamo area, Venezuela. *Can. Mineral.*, 2000, **38**(6), 1347–1370.
26. Sobolev, N. V., Yefimova, E. S., Channer, D. M. D., Anderson, P. F. N. and Barron, K. M., Unusual upper mantle beneath Guaniamo, Guyana shield, Venezuela: evidence from diamond inclusions. *Geology*, 1998, **26**(11), 971–974.
27. Kaminsky, F. V., Sablukov, S. M., Sablukova, L. I. and Channer, D. M., Neoproterozoic 'anomalous' kimberlite of Guanaimo, Venezuala: mica kimberlites of 'isotopic transitional' type. *Lithos*, 2004, **76**, 565–590.
28. Bai, W.-J., Zhou, M.-F. and Robinson, P. T., Possibly diamond-bearing mantle peridotites and podiform chromitites in the Luobusa and Donqiao ophiolites, Tibet. *Can. J. Earth Sci.*, 1993, **30**, 650–1659.
29. Yang, J.-S., Robinson, P. T. and Dilek, Y., Diamonds in ophiolites. *Elements*, 2014, **10**, 127–130.
30. Yang, J.-S., Dobrzhinetskaya, L., Bai, W.-J., Fang, Q.-S., Robinson, P. T., Zhang, J. and Green (II), H. W., Diamond- and coesite-bearing chromitites from the Luobusa ophiolite, Tibet. *Geology*, 2007, **35**, 875–878.
31. Yang, J.-S., Robinson, P. T., Xu, X. Z. and Dilek, Y., Ophiolite-type diamond: A new occurrence of diamond on the earth. *Geophys. Res. Abstr.*, 2013, **15**, EGU2013-13613.
32. Bai, W. J. *et al.*, The PGE and base-metal alloys in the podiform chromitites of the Luobusa ophiolite, southern Tibet. *Can. Mineral.*, 2000, **38**, 585–598.
33. Griffin, W. L., Yang, J.-S., Robinson, P., Howell. D., Shi, R. D., O'Reilly, S. Y. and Pearson, N. J., Going up or going down? Diamonds and super-reducing UHP assemblages in ophiolitic mantle. *Mineral. Mag.*, 2013, **77**, 1215.
34. Dilek, Y. and Furnes, H., Ophiolite genesis and global tectonics: geochemical and tectonic fingerprinting of ancient oceanic lithosphere. *GSA Bull.*, 2011, **123**, 387–411.

ACKNOWLEDGEMENTS. Preliminary petrographic studies were carried out at the CSIR-National Metallurgical Laboratory, Jamshedpur, followed by a detailed investigation at the Institute of Mineralogy and Economic Geology, RWTH Aachen University, Germany, where facilities such as EPMA and QEMSCAN were utilized. The visit of B.N. to RWTH was financially supported by the Alexander von Humboldt Foundation, Bonn, Germany.

Received 27 April 2016; revised accepted 15 June 2016

doi: 10.18520/cs/v112/i01/155-160

Haemocyte morphology and differential haemocyte counts of giant ladybird beetle, *Anisolemnia dilatata* (F.) (Coleoptera: Coccinellidae): a unique predator of bamboo woolly aphids

J. Majumder, D. Ghosh and B. K. Agarwala*

Department of Zoology, Tripura University, Suryamaninagar, Tripura 799 022, India

Changes in haemolymph characteristics such as differential counts of haemocytes have direct bearing on the general performance of insects. The present study was carried out to generate data on the morphology of different haemocytes and their differential counts of giant ladybird predator, *Anisolemnia dilatata* (F.), unique to woolly aphid pests of bamboo habitat. Five types of haemocytes, viz. prohaemocytes, plasmatocytes, granulocytes, spherulocytes and oenocytes were morphologically characterized in the haemolymph of larvae, pupae, virgin females and males. Among these, plasmatocytes were dominant followed by granulocytes, prohaemocytes, spherulocytes and oenocytes. Granulocytes showed consistency in numbers in all life cycle stages from first instar larva to adults of males and females of the giant ladybird.

Keywords: *Anisolemnia dilatata*, bamboo habitat, differential haemocyte count, giant coccinellid predator, woolly aphids.

HAEMOLYMPH of insects consists of fluid plasma and haemocytes. Numbers and sizes of circulating haemocytes vary in relation to age and life cycle stage of insects. Haemolymph constitutes 5–40% of the total body weight[1] and performs several functions such as metabolic, endocrine, reproductive, phagocytosis, encapsulation of parasites and pathogens, detoxification, immunological and in transport of essential materials between cells, tissues and organs[2,3]. Profound biochemical changes occur in the haemolymph during metamorphosis. Haemocyte count of insects is a good indicator of their physiological preparations during growth and adulthood[4] because pathogens are important factor of mortality in all developmental stages[5]. A majority of the existing studies on haemolymph are confined to the insects of families Lepidoptera, Orthoptera, Diptera, Hemiptera and Hymenoptera[6–9], and a few studies exist on coleopteran insects[5,10–13] including the only study on the beetle of Coccinellidae, *Coccinella septempunctata* L., which is a generalist predator of aphids[13]. The aim of this study was to document the

*For correspondence. (e-mail: bagarwala00@gmail.com)