

## Characteristics of modulating VLF hiss observed at Indian Antarctic Station, Maitri ( $L = 4.5$ )

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**Very low frequency (VLF) hiss emissions were observed for the first time at the Indian Antarctic Station, Maitri (geographic lat. 70°46'S, long. 11°50'E, geomagnetic lat. 66°03'S, long. 53°21'E) with the modulating intensity variations. Various spectrograms of modulating VLF hiss emissions clearly show band limited spectra regularly modulating its intensity with almost equal period of the order of few seconds in the frequency range of 9–12.8 kHz. To explain these modulating characteristics of VLF hiss, we propose that the hiss emissions are generated through Doppler-shifted cyclotron interactions near the geomagnetic equator and propagate towards the Earth in the whistler-mode. Further, the micropulsations propagating along the geomagnetic field lines could modulate the growth rate of the wave. The growth rates of the waves are also computed.**

**Keywords:** Magnetosphere, VLF emissions, VLF hiss, wave propagation, whistler-mode waves.

WAVE-particle interaction occurring in the magnetosphere generates a variety of emissions in the very low frequency (VLF) range. VLF emissions having periodic or quasi-periodic (QP) structures with periods ranging from less than a second to several minutes have been reported<sup>1–7</sup>. Amplitude-modulated VLF emissions observed on ground were classified by Helliwell<sup>8</sup>, who noted various types of periodic emissions, which usually had periods of a few seconds and were often associated with whistler-mode waves echoing along geomagnetically field-aligned paths between opposite hemispheres. QP emissions were further classified into types I and II by Sato *et al.*<sup>1</sup> on the basis of whether or not they were correlated with geomagnetic pulsations. Good correlation between the pulsing hiss periods with magnetic pulsations were reported<sup>2,9</sup>. Later on detailed comparative study of pulsing hiss recorded on board the GEOS-2 satellite, pulsating aurora observed with a ground TV camera and the ground-detected micropulsations were made<sup>3,9,10</sup>. Vero *et al.*<sup>11</sup> suggested that whistler ducts and geomagnetic field line shells may be connected with each

other. Amplitude modulations of periodic and QP VLF emissions at high latitudes in two period's ranges 4–6 s and 10–60 s have been reported by Smith *et al.*<sup>12</sup>. Marcz and Vero<sup>13</sup> have analysed micropulsations and whistler data recorded at mid-latitudes and concluded that certain structures in the magnetosphere such as field-line shells, whistler ducts, path for wave packets and particle precipitation appears together, suggesting some link between them.

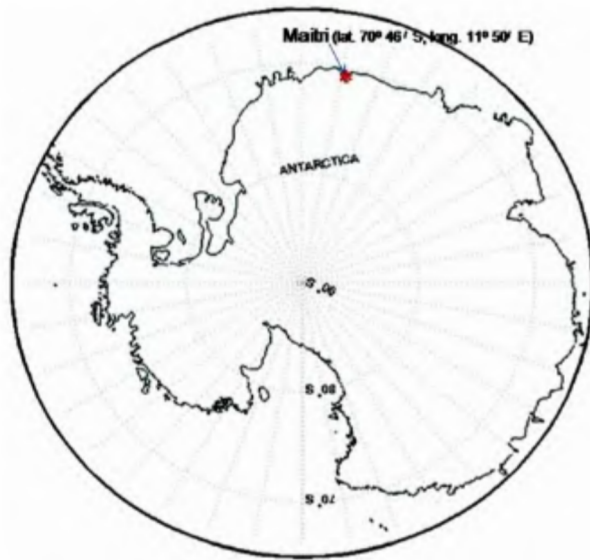
The generation mechanism of VLF hiss is considered to be a Doppler-shifted cyclotron resonance interaction in which pitch-angle anisotropy in the distribution function plays a significant role<sup>9,14</sup>. In order to interpret dynamic spectra of hiss associated with the observed intensity modulation, one should know the generation and propagation mechanism of the emissions, the source region and the energy source. In order to get modulation in intensity of the dynamic spectra of hiss, one of the given mechanisms should have a pulsing nature. Micropulsations are known to be of ionospheric origin<sup>15</sup>. The particle precipitation causes fluctuations in ionospheric conductivity<sup>16</sup> which may cause these fluctuations<sup>17</sup>. Davidson and Chiu<sup>18</sup> proposed a nonlinear mechanism for auroral pulsations, which may also be considered as a possible origin of pulsing hiss. Singh *et al.*<sup>5</sup> showed that the ultra low frequency (ULF) waves propagating along dipolar field lines modulate the geomagnetic field and produce pulsation in the hiss structure through changing growth rates.

Although VLF emissions are often observed at the Indian Antarctic Station, Maitri, there is almost no evidence of the occurrence of hiss with modulating intensities<sup>19</sup>. Here we present the observations of hiss emissions associated with the observed intensity modulation for the first time at the Maitri station. The experimental set-up and spectral analysis of observed dynamic spectra of modulating hiss are presented in the next section. To explain the observed dynamic spectra of intensity modulated hiss, we consider that the generation mechanism of hiss emission is controlled by the micropulsations propagating along the local magnetic field lines, which modulate the generation process by modulating the local magnetic field. The generation mechanism is presented in the penultimate section. Finally, the conclusion of the study is given in the last section.

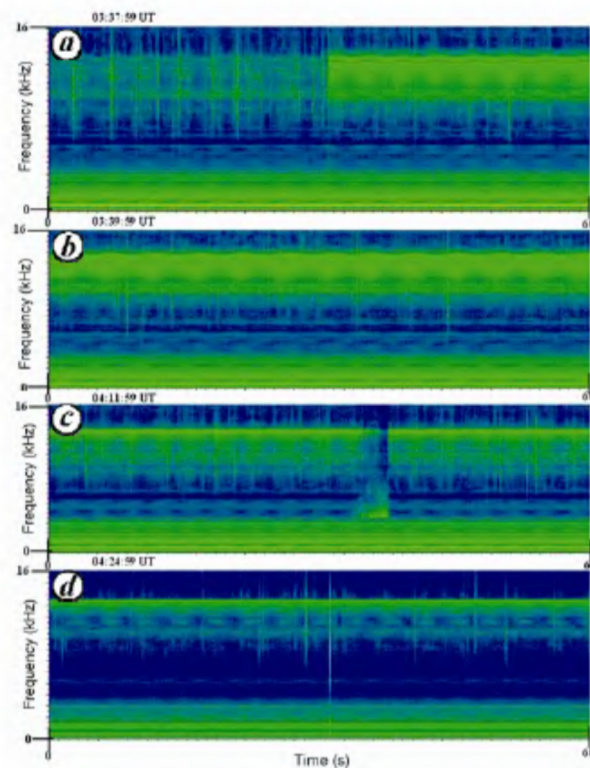
VLF wave recording set-up consisting of T-type (vertical) antenna of 10 m height and 40 m horizontal length supported by two poles, transistorized amplifiers and digital audio tape recorder is used to record VLF data at the Maitri station. The location of Maitri station containing the recording set-up (geographic lat. 70°46'S, long. 11°50'E) is shown in Figure 1. Observations were carried out at the Department of Physics, Banaras Hindu University, Varanasi during summer of the 20th Antarctica expedition from 10 January to 10 March 2001. Pre-amplifier is kept at the bottom of the pole at which an

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antenna is installed to amplify by main-amplifier and recorded using the digital audio tape recorder on magnetic tapes<sup>19</sup>. The VLF data recorded on magnetic tapes were



**Figure 1.** Location of Indian Antarctic Station, Maitri.



**Figure 2.** Typical dynamic spectra of the VLF hiss emissions associated with the intensity modulations recorded on 2 February 2001 during the period 03:37 to 04:25 UT at the Indian Antarctic Station, Maitri.

analysed using analysis software 'Raven' installed at Atmospheric Research Laboratory, Department of Physics, Banaras Hindu University, Varanasi. Raven is a software application for the acquisition, visualization, measurement and analysis of various types of sound signals ([www.birds.cornell.edu/brp/raven/RavenOverview.html](http://www.birds.cornell.edu/brp/raven/RavenOverview.html)).

Typical dynamic spectra of the VLF hiss emissions associated with the intensity modulations recorded on 2 February 2001 during the period 03.37 to 04.25 UT at Maitri are shown in Figure 2. The VLF hiss emission started on 03.37:29 UT with modulating intensity variation and continued for about 48 min to end at 04:25:60 UT with decreased intensity. The upper cut-off frequency is about 12.5 kHz whereas lower cut-off frequency is about 9.1 kHz. From Figure 2 *a* and *b*, it is noted that the frequency spectrum of the pulses is irregular in structure and intensity. It is also seen that the upper emission boundary frequency and intensity both modulate (Figure 2 *a* and *b*). The repetition period or time period of equi-spaced pulses are about 3.45 s which are non-dispersive type. The measurement of intensity and frequency variations of Figure 2 *b* is shown in Table 1, which shows the intensity modulation. Emissions during the entire period have approximately the same frequency range and periodicity. However, intensity of the emission near the end of the event decreases with time. The diurnal variation of Dst-index, AE-index and  $K_p$ -index for the period 31 January

**Table 1.** Intensity variations of modulating hiss shown in Figure 2 *b*

Time LT (h/m/s)	Frequency (Hz)	Intensity (dB)
03:39:1.4	10994	92.9
03:39:3.64	10950	85.6
03:39:5.7	10950	91.3
03:39:8.18	10860	86.0
03:39:10.45	10950	94.5
03:39:12.72	10994	80.1
03:39:15.06	10950	91.4
03:39:17.80	10950	78.9
03:39:19.36	10994	92.8
03:39:21.99	10950	83.7
03:39:23.96	10950	90.5
03:39:26.29	10950	81.3
03:39:28.5	10950	94.5
03:39:30.29	10860	79.8
03:39:32.57	11039	90.3
03:39:34.78	10994	83.0
03:39:36.99	10950	92.0
03:39:39.26	10994	78.0
03:39:41.59	11084	93.4
03:39:43.44	10994	81.1
03:39:45.89	11128	92.2
03:39:47.62	10994	79.5
03:39:49.89	11039	91.2
03:39:52.17	10950	80.1
03:39:54.20	11039	92.0
03:39:56.17	10994	77.5
03:39:58.14	11039	91.4
03:39:59.64	11039	80.6

to 3 February 2001 is shown in Figure 3 *a-c* respectively. The observation of VLF hiss emissions is also marked by an arrow in the figure. It is seen that the event was observed in the recovery phase of a weak geomagnetic storm with minimum Dst-value of  $-45$  nT. The AE-index has peak value of  $1016$  nT with the peak  $K_p$ -index value of  $4$ .

The observation of modulating hiss suggests that these emissions would have been generated near the equatorial region of  $L$ -value corresponding to the recording station ( $L = 4.5$ ) and may have propagated in whistler-mode. The other possibility is that it may have been generated at high/low  $L$ -value, in that case the emission could have traversed magnetospheric path in ducted whistler-mode and after exiting from the duct could excite the Earth-ionosphere waveguide and may have propagated towards the pole to be received at Maitri station. The upper boundary frequency (UBF) method<sup>21</sup> has been generally used to find out the location of the ground observed VLF emissions<sup>7,20</sup>. The UBF of the ground observed VLF emissions are determined on the assumption of dipolar geomagnetic field configuration, by the half electron gyrofrequency region irrespective of the observation station. The  $L$ -value of the VLF source is then computed with the help of the relation<sup>21</sup>

$$L = \left( \frac{440}{f_{UB}} \right)^{1/3}, \quad (1)$$

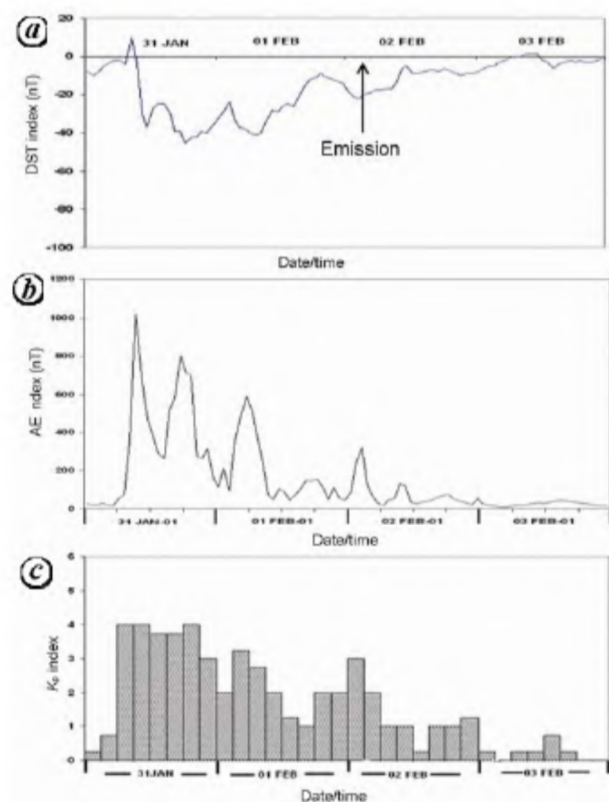
where  $f_{UB}$  is upper boundary frequency of the emission in kHz. Using eq. (1) and the observed parameters, the value of source region of the modulating VLF hiss is found to be  $L = 3.28$ . This supports the second possibility discussed above that it may have generated at lower  $L$ -value ( $L = 3.28$ ).

We now discuss the tentative generation mechanism of modulating hiss emission which requires information of propagational features, the existence of source of energy and the coupling mechanism which can convert a fraction of source energy to the electromagnetic energy in the form of modulating hiss. In the absence of arrival direction measurements, it is not possible to state exactly on which field-line the event originated. Modulating hiss observed on the ground may have propagated along a geomagnetic field line in either the ducted or non-ducted mode. The source of energy could be charged particles populating the ionosphere and magnetosphere. Knutt and Bahnsen<sup>22</sup> suggested that the pulsed hiss type of emission is a plasmasheet associated phenomenon and depends critically on the level of anisotropy of energetic electrons ( $> 20$  keV). They further indicated that the Doppler-shifted cyclotron resonance interaction between whistler-mode wave and particles available in anisotropic distributions of energetic electron is involved in the generation of pulses hiss. Word *et al.*<sup>3</sup> first attempted to relate different types of pulsing hiss to the correspondence types of pulsation, but they failed to find any convincing correspondence between them. Davidson and Chiu<sup>18</sup> proposed a nonlinear mechanism for auroral pulsation, which may be considered as a possible origin of the pulsing hiss.

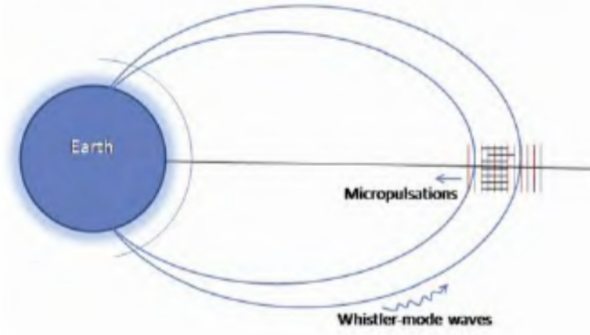
Based upon the model of Coroniti and Kennel<sup>23</sup>, Singh *et al.*<sup>5</sup> explained that whistler-mode waves propagating along geomagnetic field lines and interacting with counter streaming energetic electron scatter electrons into the loss cone, which may drive highly localized field-aligned currents leading to the generation of Alfvén wave that may set-up ULF wave along the field-lines. Thus, the equilibrium conditions breakdown when considering such fast variations and the interaction between the waves and the electron becomes a function of time. However, the condition of resonance interaction remains the same, but the physical parameters involved become a function of time. A schematic diagram to illustrate the generation of modelling hiss is shown in Figure 4. The physical whistler-mode wave growth rate  $\gamma$  is roughly<sup>23</sup>

$$\gamma \approx \Omega \eta A, \quad (2)$$

where  $\Omega$  is the local electron gyrofrequency,  $\eta$  a fraction of electron concentration near resonance and  $A = (T_{\perp}/T_{\parallel})/T_{\parallel}$  is the temperature anisotropy factor. Without the



**Figure 3.** Variation of *a*, Dst-index; *b*, AE-index and *c*,  $K_p$ -index for the period 31 January to 3 February 2001. The observation period of VLF hiss is also marked by arrow.



**Figure 4.** A schematic diagram to illustrate the generation of modulating hiss at Maitri.

observations of micropulsation, we consider model micropulsation perturbations that modify the magnetic field strength felt by resonant electrons. In this model, time varying magnetic field  $B(t)$  is written as

$$B(t) = B_0(1 + b \sin \omega_0 t), \quad (3)$$

where  $B_0$  is the background dipolar magnetic field,  $\omega_0$  the micropulsation frequency and  $b$  the normalized amplitude of the propagating micropulsation/ULF wave ( $b \ll 1$ ). Considering the parameters in eq. (2) as time dependent functions and differentiating eq. (2) by separating the variables, we obtain<sup>23</sup>

$$\frac{d \ln \gamma}{dt} = \frac{d \ln B}{dt} + \frac{d \ln A}{dt} + \frac{d \ln \eta}{dt}. \quad (4)$$

The perturbation of local magnetic field affects all the three terms on the right-hand side of eq. (4) because a change in  $B$  implies a change in  $\Omega$ , which governs the proposed mechanism of hiss generation through the Doppler shifted cyclotron resonance condition  $\omega - kv = \Omega$ . Thus a change in  $\Omega$  is directly linked with change in  $\gamma$ .

First adiabatic invariant conservation implies that  $T_{\perp} \propto B$ . Assuming that  $T_{\parallel}$  does not vary strongly, we may estimate

$$\frac{d \ln \gamma}{dt} = \left( \frac{1+A}{A} \right) \left( \frac{d \ln B}{dt} \right). \quad (5)$$

Assuming a Maxwell distribution in  $T_{\parallel}$

$$\eta = \left( \frac{m}{2\pi k T_{\parallel}} \right)^{1/2} \exp \left( -\frac{1}{2} m v_{\parallel}^2 / k T_{\parallel} \right), \quad (6)$$

where  $v_{\parallel} = (\omega - \Omega) / K_{\omega}$ , and therefore

$$\frac{d \ln \eta}{dt} = - \left( \frac{m}{k T_{\parallel}} \right) v_{\parallel} \left( \frac{d v_{\parallel}}{dt} \right). \quad (7)$$

Assuming  $T_{\parallel} \sim \text{constant}$ , we get<sup>3</sup>

$$\frac{d \ln \eta}{dt} = \left( \frac{e^2}{k T_{\parallel} K_{\omega}} \right) B \left( \frac{dB}{dt} \right). \quad (8)$$

Using eqs (3), (5) and (8) in eq. (4), we obtain<sup>3</sup>

$$\begin{aligned} \frac{d \ln \gamma}{dt} = & -b\omega_0 \left[ \frac{1+2A}{A} - \frac{m\Omega_0^2}{kT_{\parallel}K_{\omega}^2} \right] \frac{\sin \omega_0 t}{1+b \cos \omega_0 t} \\ & - \frac{m\Omega_0^2 b^2 \omega_0}{kT_{\parallel}K_{\omega}^2} \frac{\sin 2\omega_0 t}{1+b \cos \omega_0 t}, \end{aligned} \quad (9)$$

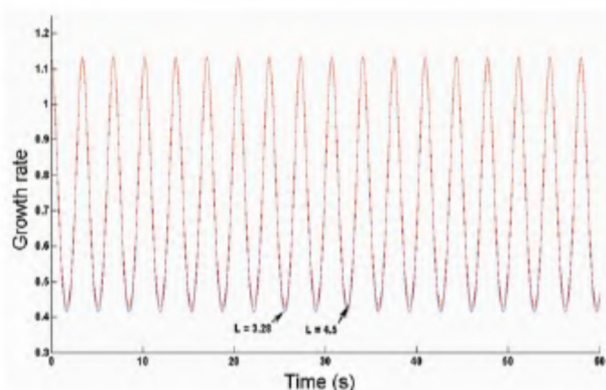
where  $m$  is mass of electron,  $k$  the Boltzmann constant,  $K_{\omega}$  the wave vector of the interacting wave. In deriving eq. (9) linear treatment has been used, i.e. the rate of change of  $\Omega$ ,  $A$  and  $\eta$  can be treated independently and the effects are linearly added. Such an analysis reveals that the modulation in hiss intensity could have two components of frequency  $\omega_0$  and  $2\omega_0$ , the former being due to the modification of  $T_{\perp}$  by changing magnetic field, whereas the latter is due to the independence of  $T_{\parallel}$  to such changes.

Integrating eq. (9), the growth rate is written as:

$$\begin{aligned} \gamma = & \left( \frac{1+b \cos \omega_0 t}{1+b} \right)^{\left( \frac{1+2A}{A} - \frac{3m\Omega_0^2}{kT_{\parallel}K_{\omega}^2} \right)} \\ & \times \exp \left[ \frac{2m\Omega_0^2 b}{kT_{\parallel}K_{\omega}^2} (\cos \omega_0 t - 1) \right]. \end{aligned} \quad (10)$$

This shows that the hiss amplitudes vary at the fundamental frequency of the micropulsations. We have computed the growth rate of hiss by numerically evaluating eq. (10) for the parameters relevant to  $L = 3.28$  and  $4.5$  which is shown in Figure 5. In the computation, we have used  $b = 0.005$ ,  $\omega_0 = 2\pi f_0$ ,  $f_0 = 0.29$  Hz,  $A = 1.5$  (refs 24 and 25),  $T_{\parallel} = 4.6615 \times 10^7$  K (ref. 26). The electron cyclotron frequency  $\Omega_0$  and the plasma frequency  $\omega_0$  are chosen corresponding to the equatorial value<sup>27</sup> for  $L = 3.28$  and  $4.5$  and wave frequency is taken as 11 kHz. The computed growth rate is found to oscillate and the amplitude of the oscillations decreases slightly as  $L$ -value increases.

From Figure 2, we observed that the modulating hiss repletion period is about 3.41 s, which corresponds to continuous micropulsation Pc1. The micropulsation Pc1 forms a standing wave pattern along the geomagnetic field-line and this produces oscillations in the fluxes of



**Figure 5.** The numerically computed growth rate of modulating hiss at  $L = 3.28$  and  $4.5$ .

trapped electron bouncing back and forth along the field lines. Thus, the wave-particle interaction is also modified. Considering the hiss emission intensity to be the result of the amplification of the waves, we expect corresponding modulation in the hiss intensity<sup>5</sup>.

The gyroresonance interaction between whistler-mode waves and energetic electrons is an important process in the magnetosphere. Its consequences are the linear wave amplification and generation of new VLF emissions, and also the wave-induced pitch angle scattering of magnetospheric particles and the associated particle precipitation into the lower ionosphere<sup>28</sup>. So, the study of modulating VLF emission observed at ground stations yields some features of the magnetosphere<sup>7</sup>. Further, high energy trapped electrons prove invaluable in assisting the evaluation of several current magnetosphere models, in particular the subject of reconnection of interplanetary geomagnetic field-lines. In the Earth's magnetosphere, whistler-mode VLF hiss plays an important role in the dynamics of radiation belts. Interactions between energetic electrons and whistler-mode waves, in particular, had been suggested as being a primary indicator in determining the morphology of radiation belts<sup>29</sup>. Thus, a detailed understanding of the generation, propagation and maintenance of modulating VLF hiss emissions observed at the Maitri station is an important problem in magnetospheric physics.

In conclusion, the observations of VLF hiss emissions with the modulating intensity variations have been reported at the Maitri station. The frequency spectrum of these hiss emissions is irregular in structure and intensity. It is also observed that the upper emission boundary frequency and intensity, both modulate.

These hiss emissions are generated in the equatorial region of lower  $L$ -values through processes of Doppler shifted cyclotron resonance mechanism. An attempt is made to explain the observed dynamic spectra by considering the modulation of the ambient magnetic field by ULF waves propagating through the source region of VLF hiss. Further, the modulated VLF hiss propagates in

the whistler-mode to reach the Indian Ground Station, Maitri. Experimental correlation between enhanced VLF hiss emissions and micropulsations is further needed to be studied to conclusively determine the exact generation mechanism of modulating hiss.

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## Diversity of arsenite-resistant cocci isolated from Hutti Gold Mine and bioreactor sample

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**Arsenite, cobalt, chromium, copper, nickel, molybdenum, selenate and selenite-resistant cocci were isolated from Hutti Gold Mine reactor and processed water samples having extreme physico-chemical characteristics of pH 1.2–8.20, conductivity 3.2–58 mS and arsenic 11.0–1443.0 mg/l. Cultural, morphological, biochemical characters and antibiotic sensitivity of all the four cocci were studied. On the basis of biochemical and Biolog® test, one isolate was identified as *Staphylococcus aureus*, and two of these were identified as *Citricoccus* sp. SRHGAs38 and *Staphylococcus* sp. SRDAs32 using 16S rRNA gene sequence. These isolates could be used for metal removal.**

**Keywords:** Arsenite resistant, Biolog®, *Citricoccus*, *Staphylococcus*, substrate utilization profile.

ARSENIC is widely distributed in the environment as a consequence of natural phenomena and anthropogenic activity<sup>1</sup>.

It is frequently found as a mineral in combination with sulphur as orpiment ( $\text{As}_2\text{S}_3$ ) and realgar ( $\text{AsS}$ ) and especially with iron and sulphur as arsenopyrite ( $\text{FeAsS}$ )<sup>2</sup>. In acid mine drainage (AMD), arsenite concentration reaches as high as 2–13 mg/l (ref. 2). All the soluble forms of arsenic, arsenite ( $\text{As}^{3+}$ ) and arsenate ( $\text{As}^{5+}$ ) are toxic to living organisms, but arsenite is more toxic than arsenate. This toxicity is due to its interference in normal phosphorylation processes<sup>1,3</sup>. Other than arsenic pollution, AMD or acid rock drainage (ARD) represents very high dissolved solids and many a time with pH as low as 2.0 (ref. 4). In spite of such extreme conditions, iron and sulphur oxidizing autotrophic organisms are the most prevalent microbes in such ecosystems, but several heterotrophic organisms comprising bacteria, fungi and actinomycetes have also been reported<sup>1,3</sup>.

Hutti Gold Mine (HGM), Karnataka, India, represents refractory gold minerals interlocked in arsenopyrite network<sup>5,6</sup>. This mine is one of the main sources for gold production in India. The presence of arsenic in the mineral, mine drainage and processed water is reported at HGM site (<http://www.minesofindia.com>), which makes the ecosystem non-conducive for the growth of microorganisms. As microorganisms present in normal soil are not usually resistant to high concentration of heavy metals<sup>7</sup>. But, they are capable of developing tolerance or resistance towards the toxic effect of metals. Species of *Bacillus*, *Achromobacter* and *Pseudomonas* are reported from arsenical ecosystems<sup>3</sup>. *P. putida* and *Alcaligenes eutrophus* were isolated from gold arsenic deposits of Kazakhstan<sup>3</sup>. *P. arseniteoxidans* was able to grow through chemoautotrophic oxidation of arsenite whereas, arsenite oxidizer Nt-26 isolate is reported to grow heterotrophically<sup>2,3</sup>.

Till date, no reports are available on diversity of arsenite-resistant heterotrophic cocci community from Indian mines. Thus, the aim of the present work was to study the diversity of arsenite-resistant heterotrophic cocci from arsenopyrite HGM and refractory gold concentrate bioreactor ecosystem.

Water samples were collected from refractory gold concentrate biooxidation reactor, storage tank of the bioreactor effluent and gold mine processed water of HGM situated in Raichur district, Karnataka, India.

Physico-chemical parameters such as colour, pH, redox potential, conductivity, salinity and total dissolved solids (TDS) were analysed by standard methods using respective portable meters (model – Eutech, Singapore). Ferrous iron was determined by diphenylamine titrimetric method<sup>8</sup>, total iron by 1,10-phenanthroline method and total arsenic with silver diethyldithiocarbamate and atomic absorption spectrophotometric method<sup>9</sup>.

Collected water samples were diluted to 1:100 and 1:1000 times and 0.1 ml of the diluted samples were inoculated in triplicate on high plate count (HPC) agar and nutrient agar (Himedia, India) plates with and with-

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