voltage pulse to the top plate. More precisely, it is not possible to keep stable electron signals for long time above these rectangular bare electrodes. For this, the bulk liquid helium thickness should be higher than the gap between these electrodes, as illustrated in Figure 2. Only then the charged helium surface will be stable for longer duration.

We have demonstrated step-by-step charging process to achieve stable electron density for a long time duration. We have also found the minimum liquid helium level required to charge the surface and achieve stable electron density over ractangular electrodes arrangement. Such a charging process and stability parameters may give insights into the nature of thermal activation of 2D electrons at higher electron density over liquid helium surface and/or on a neon substrate coated with a thin helium film for potential applications in quantum computing using electrons on superfluid helium.

1. Sommer, W. T., Liquid helium as a barrier to electrons. *Phys. Rev. Lett.*, 1964, **12**, 271–273.
2. Cole, M. W. and Cohen, M. H., Image-potential induced surface bands in insulators. *Phys. Rev. Lett.*, 1969, **23**, 1238–1241.
3. Cole, M. W., Properties of image-potential-induced surface states of insulators. *Phys. Rev. A*, 1970, **2**, 4239–4252.
4. Savignac, D. and Leiderer, P., Charge-induced instability of the ^{4}He solid-superfluid interface. *Phys. Rev. Lett.*, 1982, **49**, 1869–1872.
5. Leiderer, P., Electrons at the surface of quantum systems. *J. Low. Temp. Phys.*, 1992, **87**, 247–278.
6. Crandall, R. S., Lifetime of surface-state electrons on liquid ^{4}He. I. Free electron. *Phys. Rev. A*, 1974, **9**, 1297–1304.
7. Crandall, R. S., Lifetime of surface-state electrons on liquid ^{4}He. II. Electron lattice. *Phys. Rev. A*, 1974, **10**, 1370–1379.
8. Williums, R., Crandall, R. S. and Willis, A. H., Surface states of electrons on liquid helium. *Phys. Rev. Lett.*, 1971, **26**, 7–10; Crandall, R. S. and Williums, R., Properties of electron surface states on liquid helium. *Phys. Rev. A*, 1972, **5**, 2183–2190.
9. Iye, Y., Kono, K., Kajita, K. and Sasaki, W., Escape rate of two-dimensional electrons on a liquid helium surface around 1 K. *J. Low Temp. Phys.*, 1979, **34**, 539–550.
10. Andrei, E. Y., Yücel, S. and Menna, L., Experiments on tunneling and correlations. *Phys. Rev. Lett.*, 1991, **67**, 3704–3707.

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Greenhouse gas emission and soil properties as influenced by wheat biomass burning in Vertisols of central India

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Biomass burning is a major contributor to the atmospheric carbon budget and increases the concentration of many trace gases apart from the adverse effects on soil properties. However, in many parts of India, crop residue burning is a recurrent and widespread practice for disposal of the residues after harvest of the previous crop to facilitate sowing of the succeeding crop. The residue burning on a larger scale also leads to severe atmospheric pollution. Against this backdrop, the present work was conducted to study the effect of wheat (*Triticum aestivum*) residue burning on soil properties and assess the potential greenhouse gas emission from burning of such residues on a regional scale. The study was taken up on farmers' field in Bhopal district, Madhya Pradesh, with two residue disposal methods, viz. residue burning and residue removal, for comparison with respect to their effect on soil properties and the greenhouse gas emission potential. No significant difference was observed between both methods in terms of soil organic carbon, inorganic carbon and available P content at 0–15 and 15–30 cm soil depths. Though residue burning showed favourable effect on available K content, there was reduction in the available N content in the 15–30 cm soil depth. Residue burning did not show significant effect on soil biological activity as estimated from fluorescence diacetate test. On the other hand, there was a significant adverse effect on soil structure and labile carbon content. Residue burning was estimated to result in the emission of 379 Gg C equivalent for India and 14 Gg C equivalent for MP.

Keywords: Biomass burning, greenhouse gas emission, soil properties, wheat.

CROP residue management and disposal after harvest of the previous crop is a common problem encountered by farmers of India. Less time gap between harvesting and sowing of subsequent crop, lack of requisite machinery for crop residue incorporation in the field and increased use of combine harvester to harvest wheat, leaves behind a large amount of unmanaged crop residue in the field[1]. In order to dispose of these residues quickly, farmers

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*For correspondence. (e-mail: sangeeta_2@rediffmail.com) prefer residue burning over residue incorporation or removal from the field, merely because the former is a labour-saving method. Biomass burning is estimated as a major source for the global carbon budget and many trace gases such as carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O) and other reduced gases in the troposphere[2,3]. Both CO_2 and CH_4 directly influence global warming on the Earth, whereas changes in oxidizing capacity relating to CO variability could perturb the growth rates of many greenhouse gases (GHGs). Emissions from the burning of fossil fuels and biomass have led to the creation of atmospheric brown clouds of black carbon and aerosols in various parts of the world[2]. These clouds reduce incoming surface radiation and rainfall, resulting in negative impact on growth and yield of crops[4]. Emission of CO_2 during burning of crop residues is considered neutral, as it is reabsorbed during the next growing season. However, biomass burning is one of the significant sources of atmospheric aerosols and trace gas emissions, which has also a major impact on human health[2].

On the other hand, in areas of mechanized harvesting of wheat without burning[5], the accumulation of straw on the soil surface can create a thick layer of organic waste. Conservation tillage practices are gradually gaining importance as effective mitigation options for changing climate conditions. Studies show that no tillage (NT) and reduced tillage (RT) have favourable effect on soil properties and crop performance[6]. No-till management systems require specialized machinery for seeding into heavy residues. Due to inadequate machinery for NT in India, farmers prefer residue burning or removal, to residue incorporation in the field. Retention of wheat residue in the field potentially has several favourable effects. Burning can be detrimental to soil structure and nutrient availability due to loss of soil organic matter[4,7]. Retention of unburned residues can increase nutrient conservation, reduce weed growth and conserve soil moisture. Substantial losses of C and N due to sugarcane residue burning have been reported[8]. However, the retained mulch makes tillage operations more difficult, interferes with fertilizer and herbicide applications and can immobilize nitrogen and phosphorus[9]. However, Wiedenfeld[10] found no significant difference in soil chemical properties, except soil organic carbon after three years of sugarcane trash burning and green harvesting followed by partial incorporation of residues.

The dominant crops in the Vertisols of central India are soybean in the *kharif* and wheat or chickpea in the *rabi* season. The wheat residues are normally burnt in the field for taking up the *kharif* crop. There are no studies to show the effect of residue burning and residue removal methods on succeeding crop yield and soil properties. We hypothesize that wheat residue burning and removal from field, as commonly practised by farmers of central India, will have a marked influence on soil properties and crop productivity apart from adding to GHG emission. In the present study, impact of two residue removal systems (wheat residue burning and wheat residue removal) on soil properties was assessed and GHG loading potential to the atmosphere from burning of crop residues (rice, wheat, maize, sugarcane, cotton) was estimated for India and Madhya Pradesh (MP).

This study was conducted on the farmers' fields in Bagroda village, Bhopal district, MP. The study site is located at 23°18′N lat. and 77°24′E long., at 485 m amsl. The region has a hot sub-humid climate with average annual rainfall of about 900 mm. The mean monthly maximum temperature is highest during May (40.7°C) and the mean monthly minimum temperature is lowest in January (10.4°C). The soil of study site is a noncalcareous Vertisol (*Isohyperthermic Typic Haplustert*) with sandy clay loam texture, bulk density of $1.34\ \mathrm{Mg\ m^{-3}}$ at $0.27\ \mathrm{g\ g^{-1}}$ soil moisture content, $7.2\ \mathrm{g\ kg^{-1}}$ organic carbon, less than $0.3\ \mathrm{dSm^{-1}}$ electrical conductivity and calcium as the dominant exchangeable cation in the Ap horizon.

Emissions of only two GHGs, viz. CH_4 and N_2O from crop residue burning of some major crops in India and MP (e.g. wheat, rice, maize, sugarcane and cotton) were estimated. The emissions of carbon monoxide and nitrogen oxides were not addressed because these are the gases whose greenhouse effect is indirect and has not been quantified in a 'global warming potential' value. The methodology for estimating GHG emissions from field burning of agricultural wastes is based on a report by the Intergovernmental Panel on Climate Change (IPCC)[11]. Data on rice, wheat, maize, sugarcane and cotton production were obtained from FAI statistics 2010–2011.

After harvest of wheat, the two methods of crop residue management, viz. crop residue burning and crop residue removal, were selected for study in the farmers' fields. These are the two practices of crop residue management commonly followed by farmers in MP. The predominant cropping system followed by the selected farmers is soybean–wheat. Soil samples were collected from 0–15 and 15–30 cm soil depth from crop fields with the two methods of residue disposal (where wheat residue was burnt after harvest and wheat residue was removed from field after harvest). Soil samples were collected randomly using soil cores from five points in the field. After collection, soil samples were air-dried and passed through 2 mm sieve for further analysis. Standard procedure was followed for estimation of selected soil physical, chemical and biological properties. The parameters included soil organic carbon[12], soil aggregate analysis using Yodder's apparatus[13], available N content[14], available P content[15], available K content[16], permanganate oxidizable carbon[17], fluorescence diacetate (FDA) activity and inorganic carbon content. The mean weight diameter (MWD) was calculated according to procedure developed by Kemper and Rosenau[18]. For this, the soil sample was passed through an 8 mm sieve prior to

Table 1. Effect of wheat residue burning and removal on soil properties

	Crop residue burned		Crop residue removed	
	Soil depth (cm)		Soil depth (cm)	
Soil properties	0–15	15–30	0–15	15–30
Organic carbon (%)	0.71Aa	0.59Ab	0.72Aa	0.58Ab
Inorganic carbon (%)	0.27Aa	0.28Aa	0.28Aa	0.29Aa
Permanganate oxidizable (labile) carbon (mg/kg)	190.50Ab	208.13Aa	198.00Aa	150.00Bb
Mean weight diameter (mm)	0.64Ba	0.57Ab	0.71Aa	0.56Ab
Available N (kg/ha)	226.84Aa	192.08Ab	252.45Aa	178.49Bb
Fluorescence diacetate (μg/g/hr)	25.85Aa	25.52Aa	24.62Aa	22.95Aa
Soybean yield (mg/ha)	2.5a		2.2a	

For a given depth layer, capital letters mark significant differences between treatments ($P < 0.05$). For a given treatment, lower-case letters mark significant differences between depth layers ($P < 0.05$).

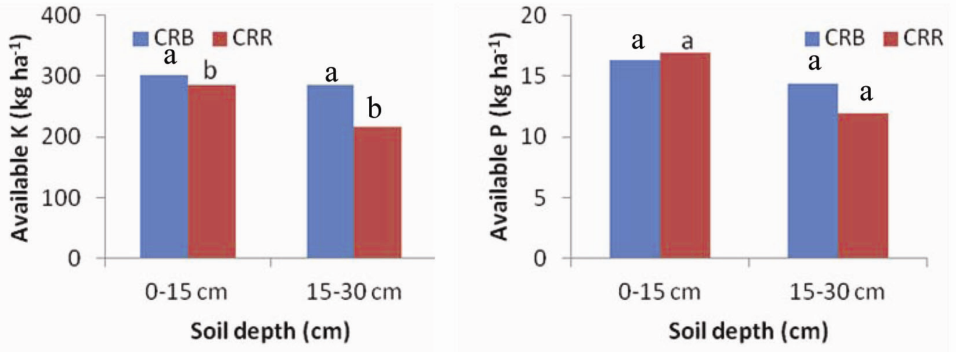

Figure 1. Effect of crop residue burning (CRB) and crop residue removal (CRR) on available K and available P contents at 0–15 and 15–30 cm soil depth. Lower-case letters mark significant differences between treatments ($P < 0.05$).

analysis. The MWD is equal to the sum of the products of the mean diameter (d_i) of each size fraction and the proportion of the total sample weight (w_i) occurring in the corresponding size fraction, where the summation is carried out over all n size fractions, including one that passes through the finest sieve (eq. (1)).

$$\mathrm{MWD} = \sum_{i=1}^{n} d_i w_i. \tag{1}$$

The data were presented as mean values. They were tested for statistical significance by Student's unpaired *t*-test. No assumptions were made on normality and variance equality[19].

The influence of wheat residue burning and removal after harvest of wheat crop on soil properties is presented in Table 1. There was no significant difference between the two residue disposal methods on soil organic carbon (SOC), inorganic carbon, available P (Figure 1) and FDA activity in the 0–15 and 15–30 cm soil depth. However, the effect of residue burning on available N was positive at 15–30 cm soil depth (available N content of 192 kg/ha under residue burning compared to 178 kg/ha under residue removal). The insignificant effect on SOC was observed despite earlier studies reporting decrease in its levels of SOC on residue burning[4,7,20]. In contrast, there was significant difference between the two residue removal methods on labile C, MWD and available K. In the surface layer, though there was no significant difference between the two methods in terms of labile C, there was a clear difference in the 15–30 cm layer. Residue burning resulted in significantly higher labile C in the 15–30 cm layer, whereas residue removal resulted in the depletion of labile C in the subsurface layer. These indicate that burning results in higher availability of mineralizable and easily decomposed C. Souza *et al.*[7] observed that in sugarcane with burn management, the greatest proportion of total organic carbon, i.e. 74% was readily metabolizable labile C, but for sugarcane without burning, it was of 54%.

The effect of wheat residue burning on soil structure was significantly adverse, particularly in the 0–15 cm soil depth, as indicated from lowered MWD in the 0–15 cm layer. Residue burning significantly reduced MWD in the 0–15 cm soil depth from 0.71 (residue removal) to 0.64 mm (residue burning; Table 1). However, there was no significant effect of residue burning on MWD at 15–30 cm soil depth. This might be due to the fact that the intensity of residue burning is mostly concentrated on the surface soil layer. In this study, although there was no significant effect of burning on SOC, it depletes the level of labile pool of SOC at 0–15 cm soil depth. Thus reduction in labile pool of SOC has a greater negative impact on soil structure than total SOC of soil. SOC build-up or depletion also improves or deteriorates soil physical properties especially soil aggregation[21–23].

The available K content at the 0–15 and 15–30 cm soil depth also increased under residue burning (Figure 1). The results of our study are in agreement with those obtained by Mendonza *et al.*[24], where higher K levels were observed for sugarcane with burn. In addition, there was no significant effect of residue burning on FDA levels, indicating that biological activity of the soil is not much influenced by the intensity of heating experienced in the prevalent residue burning methods. It is natural that if the soil is exposed to severe heating as observed under shifting cultivation areas, the biological activity may get affected irrespective of resilience of the microbial species. The results of our study are in conformity with the findings of Liu *et al.*[25], who reported no significant effect of residue burning on soil microbial biomass and soil respiration.

The multiple effects of crop residue burning, its direct effect on depleting and deteriorating soil health and its indirect but additive effects on GHG emission in the atmosphere are shown in Tables 2 and 3. Methane and nitrous oxide emissions from the burning of different crop residue as estimated for MP and India for the year 2010–11, are presented in Tables 2 and 3 respectively. The data show that in MP, wheat residue burning contributes maximum, i.e. 65% of total emission (Table 2) due to burning followed by rice and maize. However, for the country as a whole, sugarcane and rice residue burning constitutes 37% and 30% of total all-India emissions due to burning (Table 3). In India, the total emission from burning of crop residues is 379.45 Gg C equivalent compared to 13.63 Gg C equivalent in MP. Crop residue burning is considered as a major source of CO_2, CO, CH_4, volatile organic compounds, nitrogen oxides and halogen compounds[2,3].

Table 2. Effect of burning of different crop residues on methane and nitrous oxide emissions in Madhya Pradesh for the year 2010–11

Crop type	CH_4 emitted (Gg carbon equivalent)	N_2O emitted (Gg carbon equivalent)	Total emissions (Gg carbon equivalent)
Wheat	7.63	1.19	8.82
Rice	1.17	0.46	1.62
Maize	1.05	0.34	1.39
Sugarcane	1.00	0.23	1.23
Cotton	0.50	0.07	0.57
Total	11.34	2.29	13.63

Table 3. Effect of burning of different crop residues on methane and nitrous oxide emissions in India for the year 2010–11

Crop type	CH_4 emitted (Gg carbon equivalent)	N_2O emitted (Gg carbon equivalent)	Total emissions (Gg carbon equivalent)
Wheat	73.32	11.42	84.74
Rice	82.37	32.44	114.81
Maize	16.74	5.50	22.24
Sugarcane	115.12	26.48	141.60
Cotton	14.06	2.01	16.07
Total	301.60	77.85	379.45

Thus we can conclude the following from the present study:

1. There is no significant difference between the two residue management systems (wheat residue burning and removal) with regard to SOC, available N, available P content in the soil and biological activity.
2. Though wheat residue burning increases the labile C content in the 15–30 cm soil layer, it affects the soil structure as indicated by adverse effect on MWD in the 0–15 cm soil layer.
3. Apart from the effect on soil properties, crop residue burning also has additive effect of GHG emission. The total GHG emission from residue burning was estimated to be 379 Gg C equivalent for India and 14 Gg C equivalent for MP.
4. Though crop residue burning is considered as a quick, easy and labour-saving residue disposal method, it is required to advocate the benefits of crop residue recycling and *in situ* incorporation due to the global warming potential of residue burning.

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1. Lenka, S., Lenka, N. K. and Subba Rao, A., Greenhouse effect and contribution of Indian agriculture. In *Climate Change and Natural Resource Management* (eds Lenka, S. *et al.*), New India Publishing Agency, New Delhi, 2013, pp. 1–18.
2. Andreae, M. O. and Merlet, P., Emission of trace gases and aerosols from biomass burning. *Global Biogeochem. Cycles*, 2001, **15**, 955–966.
3. Guyon, P. *et al.*, Airborne measurements of trace gas and aerosol particle emissions from biomass burning in Amazonia. *Atmos. Chem. Phys.*, 2005, **5**, 2989–3002.
4. Noble, A. D., Moody, P. and Berthelsen, S., Influence of changed management of sugarcane on some soil chemical properties in the humid wet tropics of north Queensland. *Aust. J. Soil Res.*, 2003, **41**, 1133–1144.
5. Lenka, S., Lenka, N. K. and Chaudhary, R. S., Climate change mitigation options in agriculture. In *Climate Change and Natural Resource Management* (eds Lenka, S. *et al.*), New India Publishing Agency, New Delhi, 2013, pp. 195–213.
6. Singh, R. C., Lenka, S. and Singh, C. D., Conservation tillage and manure effect on soil aggregation, yield and energy requirement for wheat in Vertisols. *Indian J. Agric. Sci.*, 2014, **84**, 267–271.
7. Souza, R. A., Telles, S. T., Machado, W., Hungria, M., Filho, J. T. and Guimaraes, M. F., Effects of sugarcane harvesting with burning on the chemical and microbiological properties of the soil. *Agric. Ecosyst. Environ.*, 2012, **155**, 1–6.

8. Ball-Coelho, B., Tiessen, H., Stewart, J. W. B., Salcedo, I. H. and Sampaio, E. V. S. B., Residue management effects on sugarcane yield and soil properties in Northeastern Brazil. *Agron. J.*, 1993, **85**, 1004–1008.
9. Ng Kee Kwong, K. F., Deville, J., Cavalot, P. C. and Riviere, V., Value of cane trash in nitrogen nutrition of sugarcane. *Plant Soil*, 1987, **102**, 79–83.
10. Wiedenfeld, B., Effects of green harvesting vs burning on soil properties, growth and yield of sugarcane in South Texas. *J. Am. Soc. Sugar Cane Technol.*, 2009, **29**, 102–109.
11. Intergovernmental Panel on Climate Change, IPCC guidelines for national GHG inventories. Institute of Global Environment Strategies, Hayama, Kanagawa, Japan, 2006; http://www.ipccnggip.iges.or.jp
12. Walkley, A. and Black, I. A., An examination of Degtjareff method for determination of soils organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.*, 1934, **34**, 29–38.
13. Yoder, R. E., A direct method of aggregate analysis and a study of the physical nature of erosion losses. *J. Am. Soc. Agron.*, 1936, **28**, 337–351.
14. Subbiah, B. V. and Asija, G. L., A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.*, 1956, **25**, 259–260.
15. Olsen, S. R., Watanabe, F. S., Cosper, H. R., Larson, W. E. and Nelson, L. B., Residual phosphorus availability in long-time rotations in calcareous soils. *Soil Sci.*, 1954, **78**, 141–151.
16. Stanford, S. and English, L., Use of flame photometer in rapid soil test of K and Ca. *Agron. J.*, 1949, **41**, 446.
17. Blair, G. J., Lefroy, R. D. B. and Lisle, L., Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural system. *Aust. J. Agric. Res.*, 1995, **46**, 1459–1466.
18. Kemper, W. D. and Rosenau, R. C., Aggregate stability and size distribution. In *Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods* (ed. Klute, A.), ASA-SSA, Madison, WI, USA, 1986, pp. 425–440.
19. Dagnelie, P., Theorie et methodes statistiques. In *Applications Agronomiques*, Presses Agronomiques de Gembloux, Gembloux, Belgium, 1975, 2nd edn.
20. Cerri, C. C., Feller, C. and Chauvel, A., Evoluc, ao das principais propriedades de um latossolo vermelho escuro apos desmatamento e cultivado por doze e cinquenta anos com cana-de-ac, ucar. Cahiers ORSTOM, Serie Pedologie, 2010.
21. Rasool, R., Kukal, S. S. and Hira, G. S., Soil organic carbon and physical properties as affected by long-term application of FYM and inorganic fertilizers in maize–wheat system. *Soil Tillage Res.*, 2008, **101**, 31–36.
22. Loss, A., Pereira, M. G., Ferreira, E. P., Santos, L. L., Beutler, S. J. and Ferraz Jr, A. S. L., Fracoes oxidaveis do carbono organico em argissolo vermelho-amarelo sob sistema de aleias. *Rev. Bras. Ci. Solo*, 2009, **33**, 867–874.
23. Lugato, E., Simonetti, G., Morari, F., Nardi, S., Berti, A. and Giardini, L., Distribution of organic and humic carbon in wet-sieved aggregates of different soils under long-term fertilization experiment. *Geoderma*, 2010, **157**, 80–85.
24. Mendonza, H. N. S., Lima, E., Anjos, L. H. C., Silva, L. A., Ceddia, M. B. and Antunes, M. V. M., Propriedades quimicas e biologicas de solo de tabuleiro cultivado com cana-de-ac, ucar com e sem queima da palhada. *Rev. Bras. Ci. Solo*, 2000, **24**, 201–207.
25. Liu, W., Xu, W., Hong, J. and Wan, S., Interannual variability of soil microbial biomass and respiration in responses to topography, annual burning and N addition in a semiarid temperate steppe. *Geoderma*, 2010, **158**, 259–267.

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Energy resources and mid-continental (stable continental region) earthquakes over India: association with mantle plume-affected regions

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In the context of the Indian lithosphere, it is observed that locations of midplate earthquakes and hydrocarbon energy resources have striking correlation with the zones of influence (or corridors) of mantle plumes and their traces. The two mantle plumes (Kerguelen and Reunion) of the Ceno–Mesozoic period have given rise to the large igneous provinces, viz. the Rajmahal Traps on the eastern and Deccan traps on the western sides of the Indian sub-continent; two more mantle plumes (Marion and Crozet) are also believed to have affected India's continental margin. These plumes rise from different mantle depths, strike the base of the lithosphere and transfer the thermo-magmatic flux upwards, which in turn cause tectonic deformation/movement, and also affect changes in the geophysical/geological characteristics of the overlying lithosphere due to magmatic underplating, metasomatism and metamorphism, and thermal cooking and also enhancement of productivity of the basins due to heat and nutrient inputs from the mantle plumes coming up from the mantle. In this context, location of the stable continental region/mid-continental earthquakes and hydrocarbon/energy resources of India falling over the zone of influence of mantle plumes is significant and can be gainfully utilized in zeroing on their occurrence.

Keywords: Cratons, hydrocarbon deposits, mid-continental earthquakes, mantle plume and trace, mobile belts.

EARTH science is most directly connected with basic necessities of the human civilization; for example, natural resources and disaster management. In the Indian context, (i) energy crunch due to ever-increasing need, and (ii) disastrous mid-continental (or unexpected stable continental region, SCR) earthquakes, have motivated multi-pronged studies to understand/explore the possible locations of the occurrences of these two factors[1–3]. The present study examines these issues in light of the concept of mantle plumes (or hotspots) and their traces (or plume path) over the lithosphere and analyses if there exists any correlation with the above two factors[4,5].

Mantle plumes and Indian lithosphere: A long geological history exists with regard to effects of mantle plumes over the Indian lithosphere. So far, consequences of

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