riety of habitats. Considering the habitat diversity of India and the observed floral differences between locations and between habitats, a conservative guess for the number of species in India should be a few hundreds and a liberal one up to a thousand. This is remarkable since the *Bergey's Manual of Systematic Bacteriology* lists only 40 species from all over the world.

This quantitative argument is backed by the novelty of some of the morphotypes. On the one hand, we have morphotypes 13 and 14 (Table 2) which can be comfortably put into existing genera but perhaps require the status of a new species, on the other, there are unidentified OTUs such as 1, 2, 4 and 9 (Table 2) which are radically different from all existing groups of myxobacteria. The morphotypes 2, 4 and 9 perhaps form one close group since they resemble in spore morphology as well as the pompom toy-like woolly spherical sporangia, but differ in sporangial size and stalk. We have not seriously pursued the taxonomy of these types but if morphological novelty reflects phylogenetic novelty, this preliminary exploration of the Western Ghats indicates that many more surprises are likely to be witnessed on further exploration.

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Arbuscular mycorrhizal fungal diversity of stressed soils of Bailadila iron ore sites in Bastar region of Madhya Pradesh

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Arbuscular mycorrhizal (AM) fungi help in sustenance and conservation of tropical plant gene pool and diversity. Iron-stressed soils of Bailadila Iron Ore Project (BIOP), Bastar, Madhya Pradesh were studied for the occurrence, distribution and diversity of these crucial microbial components of bulk soil and rhizosphere. Eighteen soil and 10 plant samples were collected. Soil pH varied between 6.5 and 7.5; N content between 0.05 and 1.25% and P content between 2 and 13 ppm. Eighty-nine species of AM fungi scattered over 6 genera were recovered. *Glomus* species were the most dominant, constituting 56.82% of the total isolates followed by *Acaulospora* (21.35%), *Scutellospora* (15.73%) and *Gigaspora* (3.37%). *Entrophospora* and *Sclerocystis* were represented by a single species each. Amongst the various species, *S. pachycaulis*, *A. scrobiculata* and *G. intraradices* were the dominant forms in order of their appearance. Natural AM infection in plants collected from various sites varied between 25 and 90%. Spore population was strikingly low in the soils (0–2000 kg^{-1} soil). There was no direct relationship between soil nutrient status and percentage of infection or spore density. All the eight species of angiosperms and a single species of pteridophyte showed an average to high level of mycorrhizal infection (25–90%). The AM dependency of the host species in the iron-stressed habitats seems to be quite high and may play a significant role in establishment under metallotoxic conditions. The capacity of the native AM isolates to survive under iron stress may be instrumental in reclamation of disturbed sites.

ARBUSCULAR mycorrhizal (AM) fungi are ubiquitous in the terrestrial habitats invading over 80% of the land plants[1–3]. Taylor *et al.*[4] have demonstrated the establishment of this mutualistic relationship as early as Lower Devonian period. The structural and functional

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aspects of this association, as evident from fossil records, appear to be quite conserved through time[5,6]. This benevolent relationship has not only helped the emergence of first land plants[7] but also supported further successional establishment in widely diversified environments, viz. agricultural soils[8], mine soils[9], coal wastes[10–12], alkaline soils[13], desert soils[14,15] and other habitats. Thus, they play a key role in sustainable conservation of tropical gene pool and diversity[16]. Furthermore, through millions of years of succession, evolution, selection and co-existence, AM fungi have helped in refining the soil quality, texture[3], structure, fertility and compatibility to suit the indigenous plant species. This microbial component of the plant rhizosphere endows a major task in determining plant species diversity[17–19] and helps in stabilizing highly complex diversity regime of the tropical forests. Unfortunately, a large number of man-made and natural ecosites have not been studied for the occurrence and the extent of dependency of the plant cover on AM fungi, particularly those representing stressed ecosystems. While plenty of literature is available on the potential role of AM fungi under conditions of low nutrient availability, there is limited information on their role under stressful and toxic concentration of metals[20].

This paper deals with the diversity and ecology of AM fungi in iron-stressed soils of Bailadila iron belt situated in the south-eastern parts of Madhya Pradesh (MP) (18.51 N and 81.21 E; ~ 1500 m above MSL) in the ecologically fragile district of Bastar. This area is known for its highly conserved diversity and the distribution of flora and fauna.

The collection sites extended between Deposit no. 5 and 14 of Bailadila Iron Ore Project (BIOP) in Bastar District of MP (Figure 1). Necessary care was taken to avoid sampling from the immediate vicinity of the mining area and thus selected sites were mostly undisturbed. A few sampling sites though distantly located and free from direct human intervention, were identified as disturbed sites as the explosion shock sent by mining activity caused the stratified substratum to slide down into bluish powdery soils. These stratified horizons were penetrated by roots of ferns and angiosperms.

The ore soils which were predominantly sandy-gravel were rich in iron content (63–70%). The top soil horizon was reddish-brown due to iron oxides; however, the subsurface fraction was bluish in colour. The vegetation was xeric-herbaceous in nature. Samples were collected during November 1996.

Rhizosphere soils up to a depth of 15 cm were excavated and soil and the root samples were stored separately in polyethylene bags. Rhizosphere soils from the slide-overs were also collected. A total of 28 samples consisting of 18 soil and 10 plants were collected.

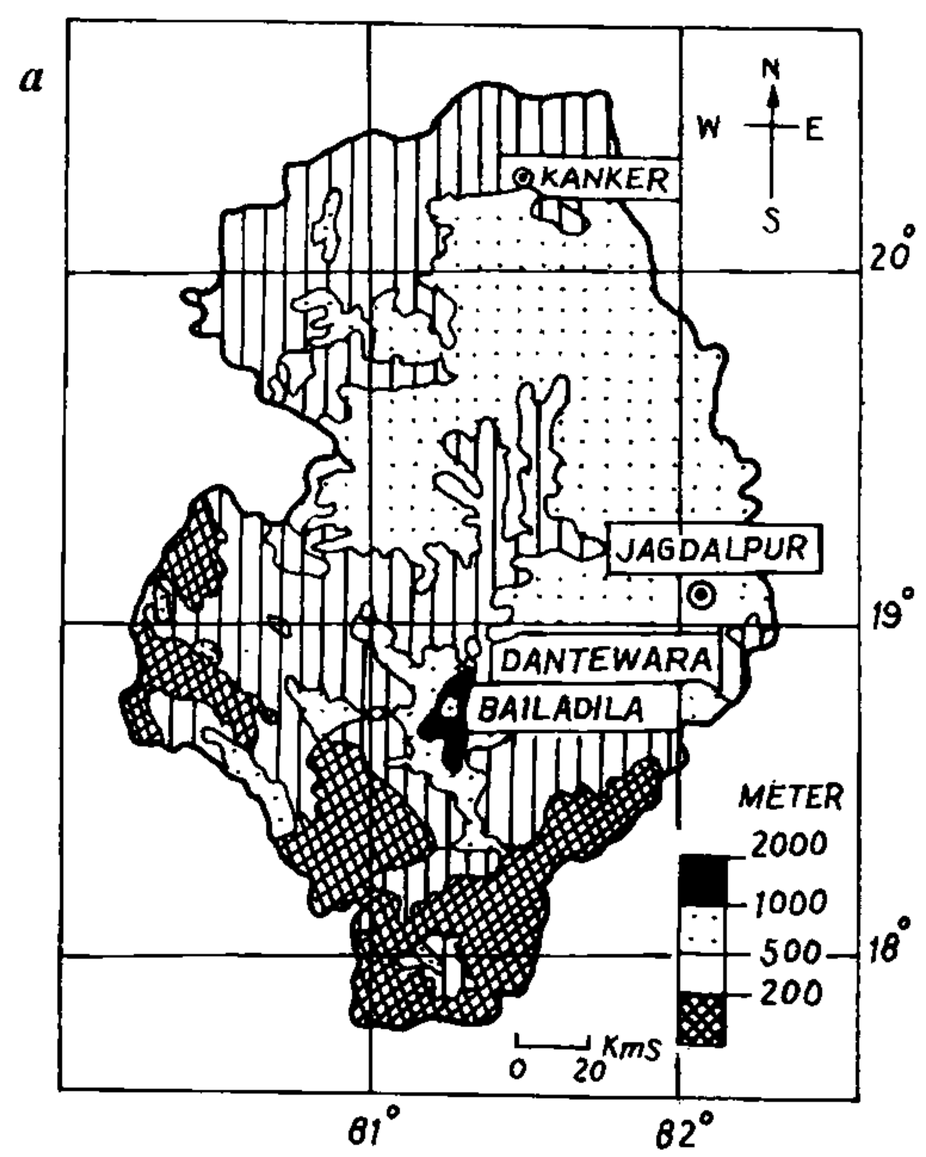

Figure 1. *a*, Location of Bailadila in district Bastar of Madhya Pradesh; *b*, distribution of sampling sites between Deposit 5 and 14.

Soils were analysed for total nitrogen (%)[21], phosphorus[22], and pH. Roots were stained with trypan blue[23] and root colonization (%) estimated by grid-line intersect method[24]. AM spore population in soil was determined

Table 1. Natural AM diversity in samples collected from iron-stressed soil and roots of Bailadila

Species and/or rhizosphere soil	% Root infection	Soil				Spore population (kg^{-1} soil)	Total no. of AM fungal species	Dominant species
		pH	N (%)	C (%)	P (ppm)			
Andropogon sp./reddish-brown; sandy-gravel	32.0 ± 0.93	6.66	0.08 ± 0.07	0.66 ± 0.04	2.68 ± 1.07	900 ± 4.48	12	*Sclerocystis pachycaulis, Glomus citricola*
Iron ore slates and slide-off sub-surface soil with scarce rhizosphere	–	6.70	0.21 ± 0.09	0.25 ± 0.06	6.15 ± 0.07	0	0	None
Rhizosphere soil from grassland	–	6.52	0.37 ± 0.18	0.32 ± 0.03	2.93 ± 0.24	1200 ± 3.82	6	*Glomus intraradices, G. citricola*
Lantana sp./rhizosphere soil; sandy-gravel	40.0 ± 1.37	6.72	0.85 ± 0.15	0.75 ± 0.06	40.00 ± 0.74	800 ± 5.30	10	*A. scrobiculata, G. mosseae, G. tenue, S. pachycaulis*
Sporobolus sp./rhizosphere soil; gravel	60.0 ± 2.33	6.70	0.29 ± 0.07	0.76 ± 0.01	2.51 ± 0.39	900 ± 5.0	7	*G. caledonium, G. geosporum, S. pachycaulis*
Argemone mexicana/rhizosphere soil; sandy-gravel	25.0 ± 1.17	7.50	0.34 ± 0.02	0.93 ± 0.02	13.00 ± 0.58	1000 ± 5.48	9	*G. reticulatum, G. intraradices, S. pachycaulis*
Phoenix sp./rhizosphere soil; sandy-gravel	35.0 ± 2.53	7.00	0.60 ± 0.05	0.72 ± 0.02	9.34 ± 0.64	1200 ± 6.29	14	*S. pachycaulis, G. citricola*
Leguminosae sp./rhizosphere soil; sandy-gravel	42.0 ± 1.37	7.35	0.58 ± 0.03	0.84 ± 0.02	9.44 ± 0.75	400 ± 4.44	10	*S. pachycaulis, G. intraradices*
Ixora sp./rhizosphere soil; sandy-gravel	75.0 ± 1.03	6.93	1.25 ± 0.11	0.69 ± 0.03	10.01 ± 0.74	1000 ± 3.16	8	*S. pachycaulis, G. reticulatum*
Fern/rhizosphere soil; sandy	66.0 ± 1.07	6.53	1.03 ± 0.13	0.58 ± 0.03	11.91 ± 0.57	200 ± 4.95	5	*A. scrobiculata, Scutellospora calospora, Gigaspora ramisporophora*
White mineral strata without vegetation cover	–	6.80	0.49 ± 0.07	0.27 ± 0.05	3.97 ± 0.15	0	0	None
Bambusa sp./rhizosphere soil; sandy-gravel	90.0 ± 0.91	7.25	0.05 ± 0.04	0.55 ± 0.04	2.10 ± 0.16	1500 ± 5.16	9	*S. pachycaulis, G. gigantea*
Rhizosphere soil of unidentified succulent species growing on slide-off ore piles; sandy	–	6.55	0.08 ± 0.03	0.80 ± 0.03	2.00 ± 0.13	1200 ± 7.22	7	*A. scrobiculata, G. geosporum, S. pachycaulis*
Rhizosphere soil of unidentified succulent species growing on slide-off ore piles; sandy	–	6.40	0.60 ± 0.02	1.25 ± 0.04	6.36 ± 0.41	2000 ± 8.06	9	*A. scrobiculata, G. geosporum, S. pachycaulis*
Moss/moss rhizosphere soil, ore slide-offs; sandy	–	6.70	0.14 ± 0.05	0.79 ± 0.04	3.91 ± 0.19	800 ± 3.53	3	*Glomus dominikii, S. pachycaulis*
Rhizosphere soil of grass on fine ore; sandy	–	7.20	0.25 ± 0.06	0.68 ± 0.04	5.23 ± 0.26	650 ± 3.53	12	*A. scrobiculata, G. citricola*
Rhizosphere soil of grass on fine ore; sandy	–	6.58	0.34 ± 0.04	0.36 ± 0.06	3.36 ± 0.20	300 ± 5.77	10	*A. scrobiculata, G. geosporum, G. magnicaule*
Rhizosphere soil from mixed vegetation on fine ore; sandy	–	6.88	0.09 ± 0.03	0.40 ± 0.03	7.72 ± 0.40	500 ± 2.24	16	*S. pachycaulis, G. mosseae, G. citricola, G. gigantea*

– No root infection.

using a modified eelworm counting slide method described by Tommercup[25]. For this, a square petri plate lined with a haemocytometer-like grid was used in place of the eelworm slide, however, the principle for calculating the number of spores essentially remained the same. The spores were initially separated on the basis of their morphology under a stereo-zoom microscope; final identification was made on permanent PVL mounts and the AM diversity spectrum profile was drawn. Identification of spore types is based on the manual for identification of VA mycorrhizal fungi[26]. Photomicrographs were taken on a Leitz–Diplan binocular research microscope fitted with photoautomatic attachment for discerning the structure and morphology of the spores.

The soils had a pH of 6.5–7.5, total nitrogen between 0.05 and 1.25% and phosphorus level of 2–13 ppm (Table 1). Eighty-nine species of AM fungi scattered over six genera, viz. *Acaulospora, Entrophospora, Gigaspora, Glomus, Sclerocystis* and *Scutellospora* were recovered; of these 23 were identified up to the species level and the rest up to the genus level (Table 2). *Glomus* species were most dominant and made up for nearly 56.82% of the total isolates; this was followed by *Acaulospora* (19 spp.), *Scutellospora* (14 spp.) and *Gigaspora* (3 spp.). *Entrophospora* and *Sclerocystis* were represented by a single species each. *Acaulospora scrobiculata, Glomus intraradices, G. caledonium, G. geosporum*, and *Sclerocystis pachycaulis* were the most dominant forms. In fact, *S. pachycaulis* was present in all but grass and fern rhizosphere samples whereas *Gigaspora ramisporophora* was recovered from the fern rhizosphere alone. Besides, numerous fern propagules were found adhered to the spore wall of *Gi. ramisporophora,* firm enough to endure washing. Many of the forms appeared strikingly new which did not fit into any of the descriptions compiled in the manual for identification of VA mycorrhizal fungi[26].

Natural AM infection of root samples varied between 25 and 90% but spore population was strikingly low in the iron-stressed soils (Table 1). The spore population size ranged between 0 and 2000 kg^{-1} soil. A white mineral strata devoid of any vegetation cover and a reddish-brown/blue stratified mineral slate and slide-off subsurface soil with rhizosphere penetration lacked any spores. Highest population counts (2000 kg^{-1}) were gathered from rhizosphere samples of an unidentified succulent species growing over a pile of ore slide-offs. On the other hand, population levels were low in fern rhizosphere and grassland rhizosphere and fine ore soils from rhizosphere of a leguminous species. Contrary to the low propagule density, the AM diversity spectrum was, however, amazingly large with 89 species. A total of 147 isolates in 16 rhizosphere samples were recorded. Maximum number of species was observed in rhizosphere samples supporting mixed vegetation canopy (16 species), followed by *Phoenix* rhizosphere (14 species). *Andropogon* rhizosphere and grass rhizosphere had 12 species each. The least number of species was found in moss (3) and fern (5) rhizospheres. This reveals a highly specific consortium to each rhizosphere with a high degree of variance in species composition of each species mix. Hence, a very high AM diversity index in these iron-stressed soils was apparent. There was no direct correlation among soil phosphorus, nitrogen and spore density.

Table 2. Species identified from Bailadila iron ore sites

Acaulospora dilitata Morton
Acaulospora scrobiculata Trappe
Gigaspora albida Schenck & Smith
Gi. decipiens Hall & Abott
Gi. ramisporophora, Sieverding & Schenck
Glomus caledonium (Nicolson & Gerdmann) Trappe & Gerdmann
G. citricola Tang & Zang
G. clarum Nicolson & Schenck
G. dominikii Blaszkowski
G. fecundisporum Schenck & Smith
G. fasiculatum (Thaxter) Gerdemann & Trappe emend. Walker and Koske
G. geosporum (Nicolson & Gerdmann) Walker
G. glomerulatum Sievarding
G. intraradices Schenck & Smith
G. magnicaule Hall
G. macrocarpum Tulasne & Tulasne
G. reticulatum Bhattacharjee & Mukerji
G. tenue (Greenall) Hall
Sclerocystis pachycaulis Wu & Chen
Scutellospora calospora (Nicolson & Gerdmann) Walkers & Canders
S. dipurpurescens Morton & Koske
S. minuta (Ferrer & Herrera) Walkers & Sanders
S. pellucida (Nicolson & Schenck) Walker & Sanders

The capacity of VA mycorrhizal fungi to act as biofertilizers, bioregulators and bioprotectors[27–29] has repeatedly been demonstrated. These associations help to maintain the general plant vigour under a variety of adverse and inhospitable ecological conditions[3,30]. A large number of man-made and natural habitats require detailed investigation in order to enhance our knowledge of the ecology and applicability of AM fungi in successful reclamation and restoration practices in degraded ecosystems. Man-made habitats are more or less always flanged by adjacent undisturbed zones which can behave as model systems for studying the ecology and diversity of soil microflora, evolving competent bioremediation tools and strategies specifically suited for the adjacent disturbed ecosites. Unfortunately, there is scanty information on stressed ecosystems notably with high metallotoxicity which form one of the major dwelling sites for mineral extraction. Although it would be inadequate to draw any major conclusion, as the present study comprised a small sampling size and belonged to a very small region spread across a belt of 10 km, it provided

some valuable information on the soil, its nutrient status and the wealth of AM microflora.

All eight species of angiosperms and a single pteridophyte showed an average to high level of mycorrhizal infection. The importance of endomycorrhizal symbiont in the plants inhabiting sites with high metallic toxicity has already been established[20]. Thus, it seems that there could be a significant AM dependency in the iron-stressed soils for the available AM propagules which are limited in number. The possible factors behind depleted propagule density may be, the low soil fertility, organic matter, soil texture, soil moisture[31–34] and severe soil compaction[3]. A host of other reasons like high metallic concentrations and very heavy soils (~350 cc of soil weighs 1000 g), with predominantly gravel texture might reduce the available soil milleu and space which is likely to exert significant pressure on spore production. Thus, this low density and high diversity index may be indicative of the extent of stress which ultimately provides a winning edge under stressful conditions. Bradley *et al.*[20] stated that at high level of metals, inhibition of root extension occurs and under these circumstances the presence of endomycorrhizal symbiont could be of significant use. These workers showed that non-mycorrhizal plants failed to show any growth in presence of metals (Cu and Zn), whereas mycorrhizal plants showed some growth even at the highest concentration. Nonetheless, the low population size does not result in low infection rates, as supported by Waaland and Allen[34] who found no correlation between spore counts and root infection during a study of coal surface mining sites. This implies that high magnitude of diversity and not the number is important in induction of stress tolerance in the host species.

G. ramisporophora, isolated from fern rhizosphere, had numerous spore tetrads attached firmly to its surface. The role of VAM propagules as a vector may be of considerable significance. Although such reports are virtually non-existent, they may help in extending endurance during the initial/seedling stage itself to the plant in such metallotoxic environments besides enhancing the probability of encountering the viable host under the conditions of slow and retarded root proliferation in the petrified terrain. A high degree of mycorrhizal colonization (66%) comparable with other higher plants was revealed in the fern roots. Asbjornsen and Motagini[35] showed that the fern *Nephrolepsis biserrata* had significantly greater colonization than the tree species or the grass studied. The studies of AM association in a rootless tropical aquatic fern *Salvinia cucullata*[36], and 40 other fern species[37] has already confirmed high infection rates (63.3–92%) in these pteridophytes.

Recovery of large AM diversity, from a very small sample size, bearing around 50% of the total known AM fungi not only reveals the rich wealth of VAM diversity sheltered in such stressful habitats but also that the extreme environments are centres for evolution and conservation of biodiverse gene pool. These native isolates with the capacity to survive under iron stress may be instrumental in reclamation of disturbed sites. If the magnitude of the diversity and the vector index of abiotic stress and index of functional response for stabilizing the community are known, appropriate strategies can be drawn for construction of competitive indigenous species mix (consortium)[16] which would make the reestablishment and regeneration attempts ecologically and economically viable in such constrained ecosystems. A more scientific, systematic, intense and precise approach in such studies is needed to render it applicable.

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Petrochemical studies on the epicentral region of the recent Jabalpur earthquake

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We report presence of five physically distinct and chemically dissimilar basaltic lava flows in the Kosamghat, the epicentral region of the Jabalpur earthquake. The major shift (~ 150 m) in the stratigraphic height of the fifth lava flow at the western flank of the Nagapahar range suggests the presence of a NE–SW trending post-Deccan normal fault in the region.

JABALPUR area has witnessed intensive investigations after the devastating earthquake (*M* 6) struck the Kosamghat region on 22 May 1997. Preliminary studies by Gupta *et al.*[1] on earthquake parameters, aftershocks and focal mechanism have indicated its epicentre to lie at 30 km south-east of Jabalpur near Kosamghat. Acharyya *et al.*[2] based on aftershock macroseismic and microseismic studies have delineated a 35 km long and 15 km wide, ENE–WSW trending meizoseismal zone of an intensity VIII (MSK). They also observed that five aftershocks of $M > 3.0$ and twenty-three aftershocks of $M = 1.5$ to < 3.0 were concentrated in an elongated area of 15×10 km^2 near the main shock epicentre. The epicentral region (long. 80.1°E, lat. 23.1°N), i.e. Kosamghat falls within the Deccan Trap outlier (commonly referred to in the literature as Eastern Deccan Volcanic Province) and its comprehensive stratigraphic framework is available elsewhere[3,4]. The main shock and aftershocks are considered to be the result of reactivation of a deep-rooted seismogenic ENE–WSW trending South Narmada Fault (Figures 2 and 3 in ref. 2) that lies

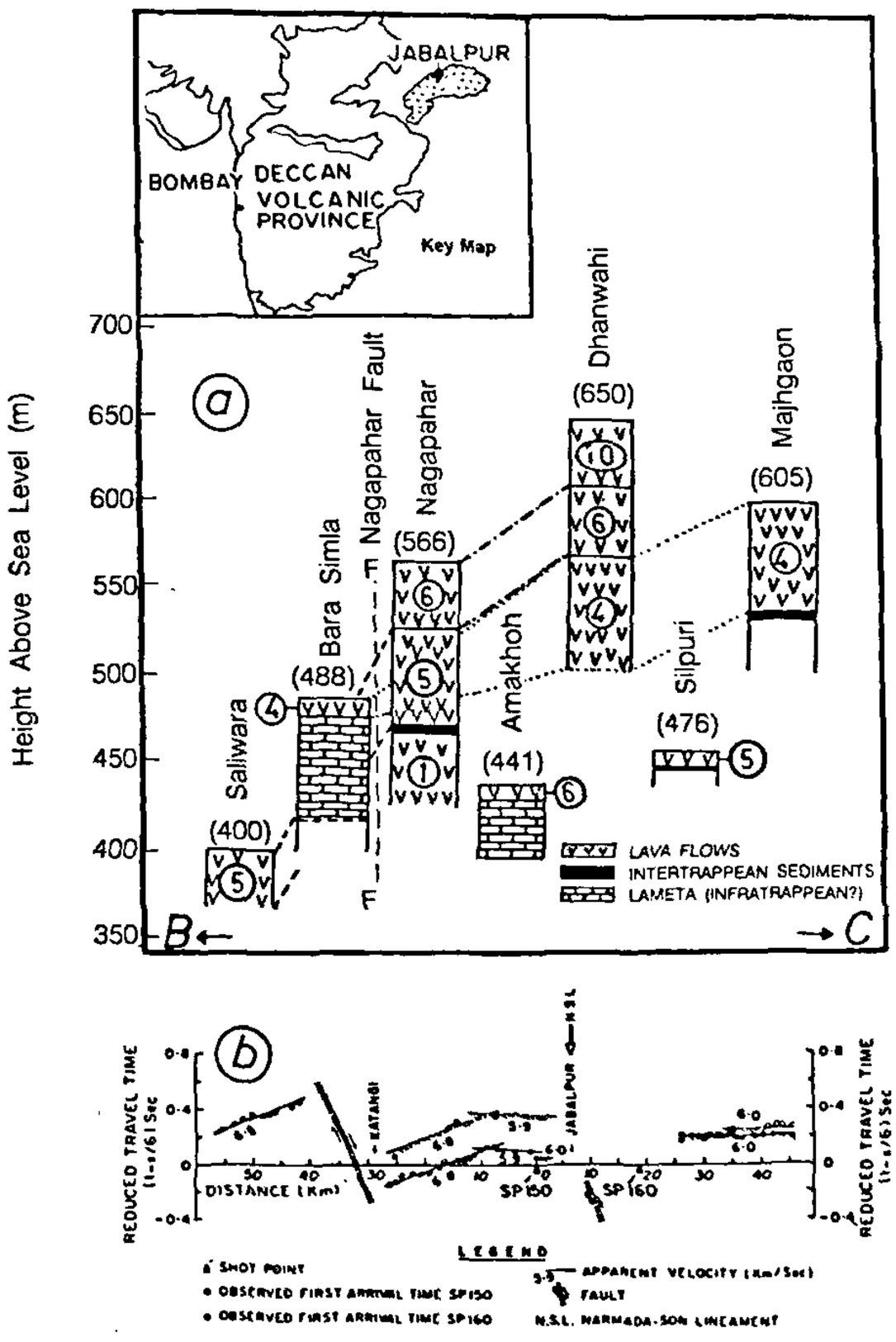

Figure 1. *a*, Stratigraphic correlation of lava flows in measured sections adjacent to Nagapahar Fault. Relative positions are from east to west along B–C traverse. The numbers encircled correpond to flow numbers (see Figure 2.5 in ref. 3); *b*, Faults shown in reduced travel time of DSS north and south of Jabalpur[11].

**For correspondence.