Precise Rb–Sr age and enriched mantle source of the Sevattur carbonatites, Tamil Nadu, South India

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Whole-rock-mineral Rb–Sr isochrons of carbonatites and pyroxenites of the Sevattur carbonatite complex, Tamil Nadu, South India, yield precise and concordant ages of 771 ± 18 Myr (million years) and 773 ± 18 Myr respectively, which are interpreted as the time of their emplacement on the basis of field and petrological evidences. Since the oxygen isotope composition ($\delta^{18}O_{SMOW} \approx +7$ ‰) of the carbonatite is typical for a mantle origin, the initial Sr ratios of 0.70521 ± 4 and 0.70536 ± 13 for the carbonatites and pyroxenites imply a substantial enrichment of their subcontinental mantle source very much or just prior to the production of the carbonatite magma 770 Ma (million years ago).

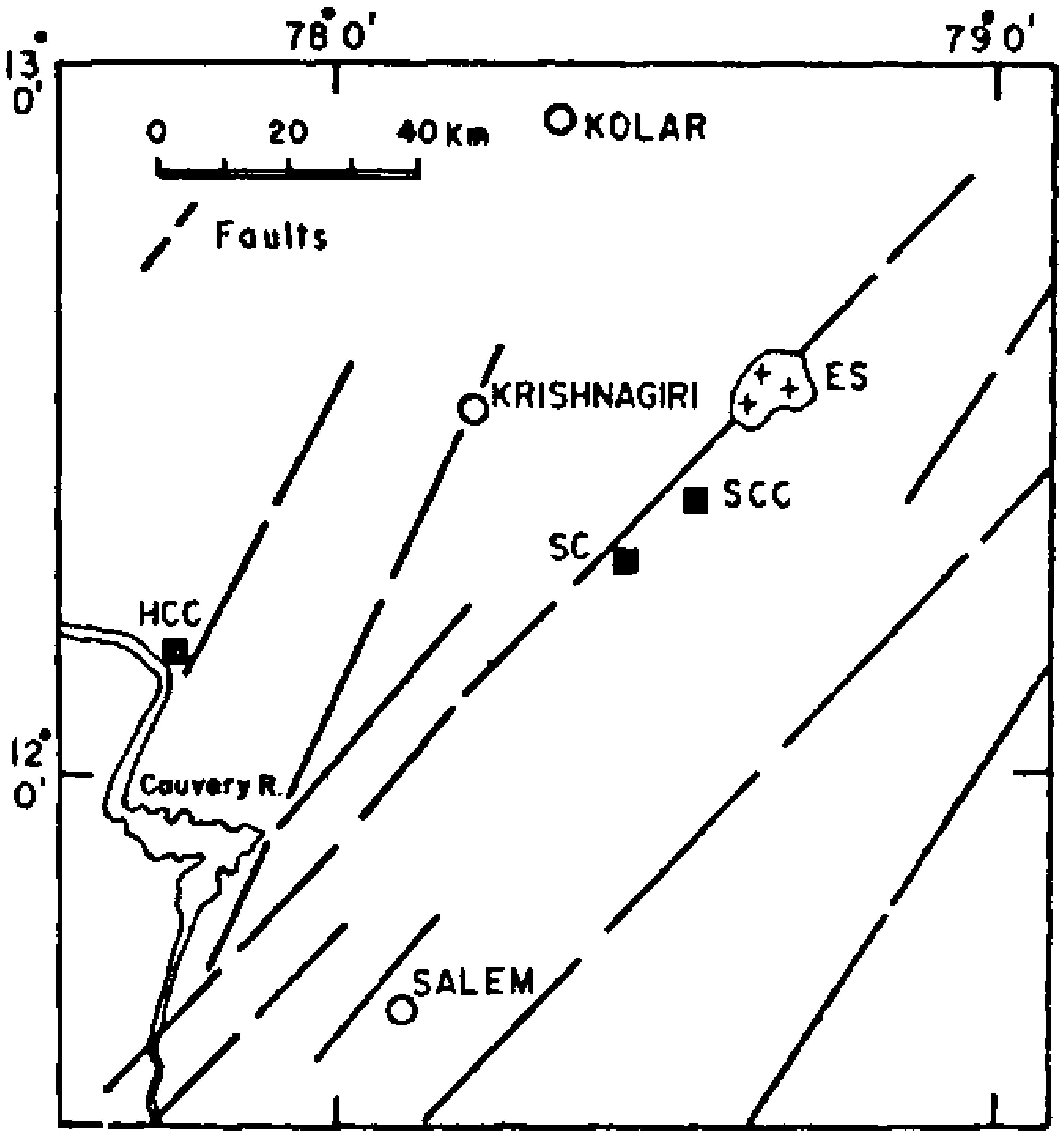

Figure 1. Map showing location of carbonatites and deep faults in the region SCC, Sevattur carbonatite complex; SC, Samalpatti carbonatite; HCC, Hogenakal carbonatite complex; ES, Elagiri syenite.

CARBONATITES are magmatic, carbonate-rich (>50 wt%) rocks derived from magma originating in the upper mantle at depths greater than 75 km (ref. 1). Of the characteristically high concentrations of P, Ba, Sr and the light rare earths in carbonatites, radiogenic isotopes of Sr and Nd have been particularly useful in inferring the evolution of their mantle source regions, since effects of crustal contamination and post-magmatic alterations are negligible in the vast majority of carbonatite occurrences.

The Sevattur carbonatite complex (SCC) (78° 32′ E, 12° 25′ N) belongs to a cluster of several carbonatite occurrences in the Dharmapuri and North Arcot districts of Tamil Nadu in South India, with all of them spatially associated with a series of NE–SW-trending major crustal faults[2] (Figure 1). SCC is intrusive into Archaean granite-gneiss and consists mainly of pyroxenite, carbonatite and syenite, with the carbonatite sandwiched between the other two rock bodies[3]. The carbonatites are mainly sovite and beforsite, with apatite, magnetite and iron-rich phlogopite as accessory minerals. The pyroxenite consists mainly of clinopyroxene, with minor amount (~5%) of biotite. Primary pyroxenite has in some places been altered into biotite pyroxenite and phlogopite-apatite-magnetite pyroxenite owing to the later intrusions of the carbonatite and syenite. The geology, mineralogy and geochemistry of SCC have been described by Krishnamurthy[3].

Carbonate and mica minerals were handpicked under a binocular microscope from a part of the crushed samples of carbonatite and pyroxenite. Rb–Sr isotopic analyses of whole rocks and minerals followed standard mass-spectrometric isotope-dilution procedures[4] with total process contamination of less than 1 ng of Rb and 3 ng of Sr and a mean value of 0.71030 ± 3 for the $^{87}Sr/^{86}Sr$ ratio of NBS-987 standard during the course of this work.

Rb–Sr isotopic abundances and ratios in the analysed samples are given in Table 1 and plotted on Sr evolution diagrams (Figure 2). Both the carbonatite and pyroxenite, together with their mineral fractions, yield well-defined isochrons corresponding to ages and initial Sr ratios of 771 ± 18 Myr (mean square of weighted deviates, MSWD, 0.35) and 0.70521 ± 4 for the carbonatite, and 773 ± 18 Myr (MSWD 0.064) and 0.70536 ± 13 for the pyroxenite.

Since the isochrons are based on whole rock and its constituent minerals, the age could refer to the time of

Table 1. Rb–Sr abundances and ratios in SCC carbonatite and pyroxenite.

	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$* (atomic)	$^{87}Sr/^{86}Sr$† (atomic)
Pyroxenite				
Whole rock	51	626	0.2376	0.70798 ± 2
Biot-1	294	70	12.26	0.84058 ± 2
Biot-2	26	2.3	33.95	1.08218 ± 8
Biot-3	290	120	7.00	0.78226 ± 3
Carbonatite				
Whole rock	0.098	4713	6.002×10^{-5}	0.70521 ± 2
Calcite	0.005	5395	2.781×10^{-5}	0.70520 ± 5
Biot-1	316	27	34.89	1.08306 ± 4
Biot-2	321	24	40.25	1.15148 ± 3
Phl.3	289	31	28.22	1.01889 ± 3

*Error less than ±2 ‰.
†Error is 2σ of the weighted mean.
$\lambda\ ^{87}Rb = 1.42 \times 10^{-11}\ y^{-1}$.

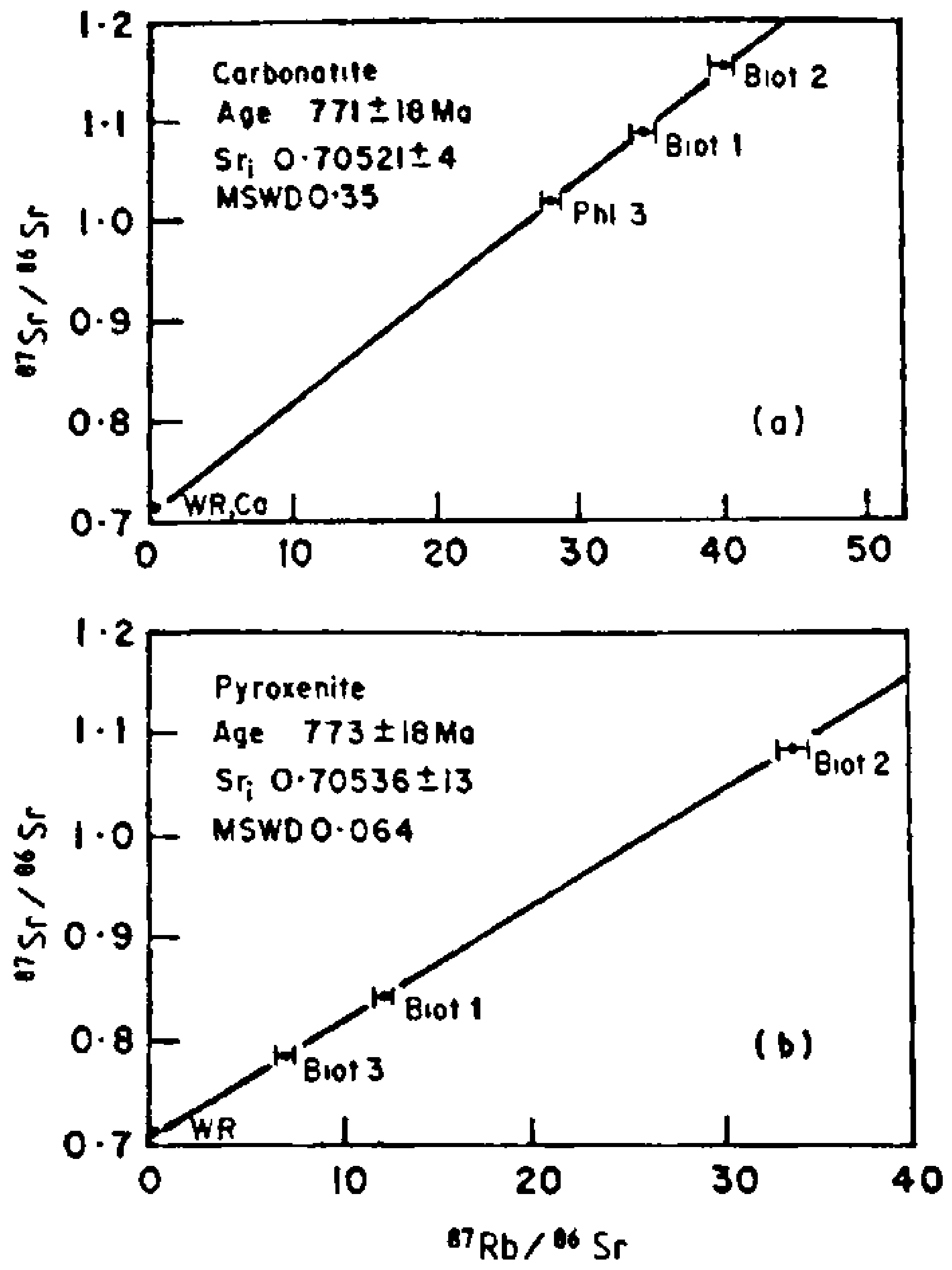

Figure 2. Whole-rock-mineral Rb–Sr isochrons for carbonatite and pyroxenite.

either their primary crystallization or later Sr-isotopic equilibration on a mineral scale due to subsequent thermal events. Apart from any lack of mineralogical evidence for metamorphic reconstitution, any mineral-scale Sr mobility is unlikely to lead to nearly identical equilibrated Sr ratios in the carbonatite and pyroxenite because of the vast difference in their Sr contents. Also noteworthy is the nearly 2-Gyr (billion-year) age, based on whole-rock-mineral isochron[5] as in the case of SCC, of the Hogenakal carbonatite (HCC) only about 70 km to the west (Figure 1). We believe therefore that the concordant internal isochron ages represent the time of emplacement of SCC. While our result is in broad agreement with the earlier K–Ar, Pb–Pb and fission-track ages for this complex (summarized by Krishnamurthy[3]), it is much more precise.

According to this interpretation of the isochron ages, the initial Sr ratios represent the Sr isotopic composition of the magma(s) from which the carbonatites and pyroxenites crystallized about 770 Ma. These two ratios are not only equal within analytical errors but also agree very well with the values reported by Deans and Powell[6] for the sovite and beforsite of SCC. They are, however, distinctly higher than that for the vast majority of carbonatites of this age group from Africa, Australia and North America[7]. While the ratios of the latter are markedly less than that of the bulk earth (ε_{Sr} negative), the Sr ratio of SCC is higher than that of the bulk earth ($\varepsilon_{Sr} \sim +22$) 770 Ma. This raises the possibility that the SCC magma is not a pristine derivative of the upper mantle but was considerably modified by assimilation of continental crust in a crustal magma chamber or during its transit through the crust. But three lines of evidence indicate insignificant crustal contamination and/or post-magmatic alteration of the mantle-derived magmatic precursor(s) of the carbonatites and pyroxenites. If the granite-gneiss country rock hosting SCC with its higher Sr ratio was assimilated in the mantle-derived magma to raise even the bulk-earth Sr ratio (0.7036) at 770 Ma to the values measured, it would imply drastic attendant changes in the abundances of Sr, P and the light rare earths. But Krishnamurthy[3] has shown that major, minor and trace elements in the Sevattur carbonatites are broadly comparable with the typical carbonatite abundance compiled by Woolley and Kempe[8]. Secondly, progressive and variable crustal contamination of the mantle-derived magmas during differentiation in a crustal magma chamber is unlikely to result in nearly identical Sr ratios for the early-forming pyroxenites and later carbonatites. It is notable in this connection that the closely situated but much older Hogenakal carbonatite shows the typical depleted-Sr signature. The third and the strongest evidence against significant crustal contamination during differentiation and post-magmatic alteration (e.g. circulation of hydrothermal fluids) comes from the oxygen isotopic composition of the Sevattur carbonatites. The average $\delta^{18}O_{SMOW}$ of 7‰ is very typical of pure mantle sources[9]. We therefore conclude that the higher Sr ratios of SCC reflect the enriched character of its mantle source. To decide whether the enrichment was caused by mantle metasomatism much earlier than 770 Ma or just prior to the melting event at 770 Ma requires further information.

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ACKNOWLEDGEMENTS. We thank Drs R. Srinivasan, P. Krishnamurthy and Y. J. Bhaskar Rao for providing the samples used in this study; Dr T. V. Sivaraman for help in the Sr isotopic analyses; and Dr S. K. Bhattacharya and Mr D. J. Patil for the stable-isotope data.

Received 10 January 1991; accepted 17 January 1991

Fossil fern *Goniopteris prolifera* Persl. from the Siwalik sediments near Nainital, North India

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Fern-leaflet (frond) impressions showing close resemblance with the modern *Goniopteris prolifera* Persl. of the family Thelypteridaceae have been recorded from the Siwalik sediments near Kathgodam in Nainital district, Uttar Pradesh, North India. This is the first record of the occurrence of fern leaflets in Siwalik sediments. The finding also suggests that the climate was possibly tropical, warm and humid during Miocene period.

THE Siwalik sediments around Kathgodam[1] are found in a northeast–southwest direction, exposed on Kathgodam–Nainital and Bhimtal road. Here the Lower Siwaliks are well developed, comprising hard, fine-grained sandstones and shales.

Plant megafossils, including petrified woods, leaf impressions, fruits and seeds, have been reported from the Siwalik sediments of Himachal Pradesh, Uttar Pradesh, Bihar and Nepal[2–4]. These plant remains mostly belong to angiosperms and palms.

Floristically, the Lower Siwalik sediments in the Kathgodam area show a rich assemblage of leaf impressions that have not been studied. Recently a large number of well-preserved leaf impressions were collected from shales in Balia riverbed west of Suriajala (29° 19′N, 79° 31′E), about 9 km north of Kathgodam on the Nainital road (Figure 1). Study of these fossils revealed the presence of fern leaflets (fronds) as well as dicot and monocot leaf impressions. The fern leaflets have been identified after consulting herbarium sheets in the herbarium of the Forest Research Institute, Dehra Dun.

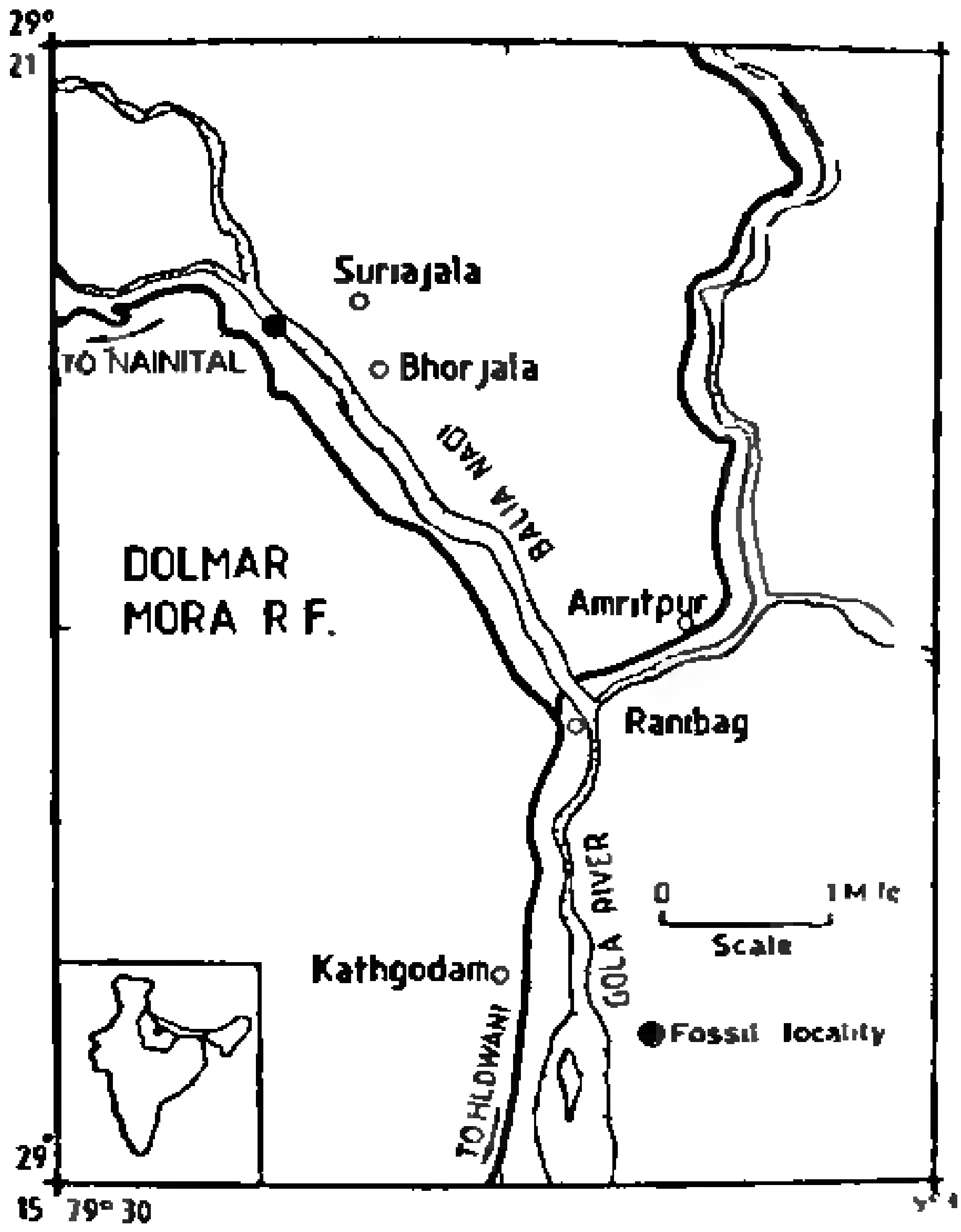

Figure 1. Map showing fossil locality.

Description: Fronds 5.5 cm × 1.0 cm and 4.6 cm × 2.0 cm in size; sessile; oblong to lanceolate shape; apex acuminate; base obtuse, seemingly auricled; margin smooth to crenulate; texture subcoriaceous; about 27 pairs of pinnules visible, vennules 5–10 pairs in each pinna, conivent at acute angle. (Figure 2,*a*,*c*).

Remarks: The shape, size and other features show similarity with the modern fronds of *Goniopteris prolifera* Persl. (FRI Herbarium sheet no. 22937a; Figure 2,*b*) of the family Thelypteridaceae.

The modern comparable fern *G. prolifera* now grows in the forests of Bengal and is very common in the Nilgiris. It grows in moist, shady places, usually along streams. Its present distribution suggests that tropical

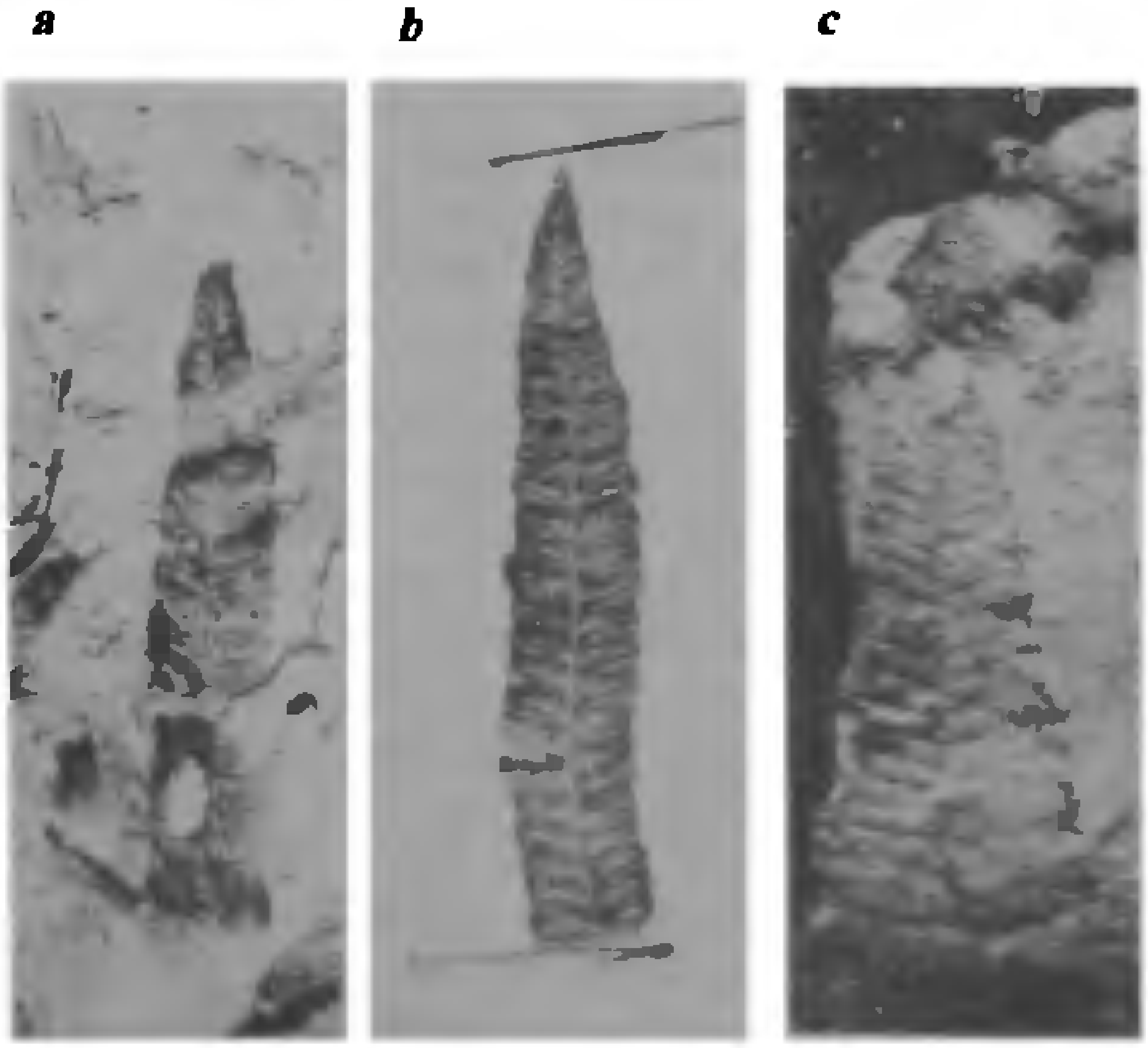

Figure 2. *a* and *c*, Fossil fronds; *b*, modern frond of *Goniopteris prolifera* Persl.