Ga magmatism and metamorphism appears to be related to a major thermal and accretional event possibly associated with the uprise of a mega-plume[23, 24]. The mega-plume caused the ascent of heat and fluids along with mantle-derived material into the continental crust, which induced large-scale melting of crust, mixing and hybridization of magmas.

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Extraordinary helium anomaly over surface rupture of September 1993 Killari earthquake, India

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An interesting helium field associated with the surface rupture of the September 1993 Killari earthquake has been discovered. Extensive soil-gas helium measurements over a 300 × 200 m area covering the rupture zone brought forth helium peaks, sharp and very high (reaching several tens of ppm as against 'regional' of 0.2 ppm), restricted to the features marking the rupture. Measurements in the immediate vicinity showed two helium 'spots' revealing concealed segments. The helium release is a clear signature of the faulting associated with the earthquake.

IMMEDIATELY following the 29 September 1993 Killari earthquake in India (also called Latur earthquake, magnitude: 6.3), a trace of surface rupture was recognized[1–3]. This trace, about 2 km from Killari, is marked by a set of gentle scarps in discontinuous segments, their cumulative length not exceeding one kilometer. Ground conditions being favourable over this trace for meaningful overburden-gas sampling, we carried out a few preliminary helium analyses during the third week of October 1993. Surprisingly high helium levels were observed which persisted even a month later. This prompted us to undertake a detailed survey (313 sites in a 300 × 200 m area). We report here the extraordinary helium anomaly which is highly restricted to the trace and its immediate vicinity (Figure 1). Helium excesses were also detected over two barely visible features few hundred metres away from this area (Figure 3), indicating that they also form part of the surface rupture. We believe helium survey provides a significant new tool in earthquake studies.

The faulting associated with an earthquake, initiated at depth, rarely penetrates to the surface and leave a significant expression. When it does, the characteristics of the surface rupture can give valuable geological insights into the regional seismogenic processes[4–6]. Johnston and Bullard[7] anticipated a surface rupture for the 1989 Ungava (Canada) earthquake because of its occurrence in Precambrian shield crust, absence of thick sediment cover, shallow focus, thrust mechanism and adequate size. All these factors also apply to the Killari earthquake and hence the occurrence of a surface rupture is not surprising. This rupture joins a very select

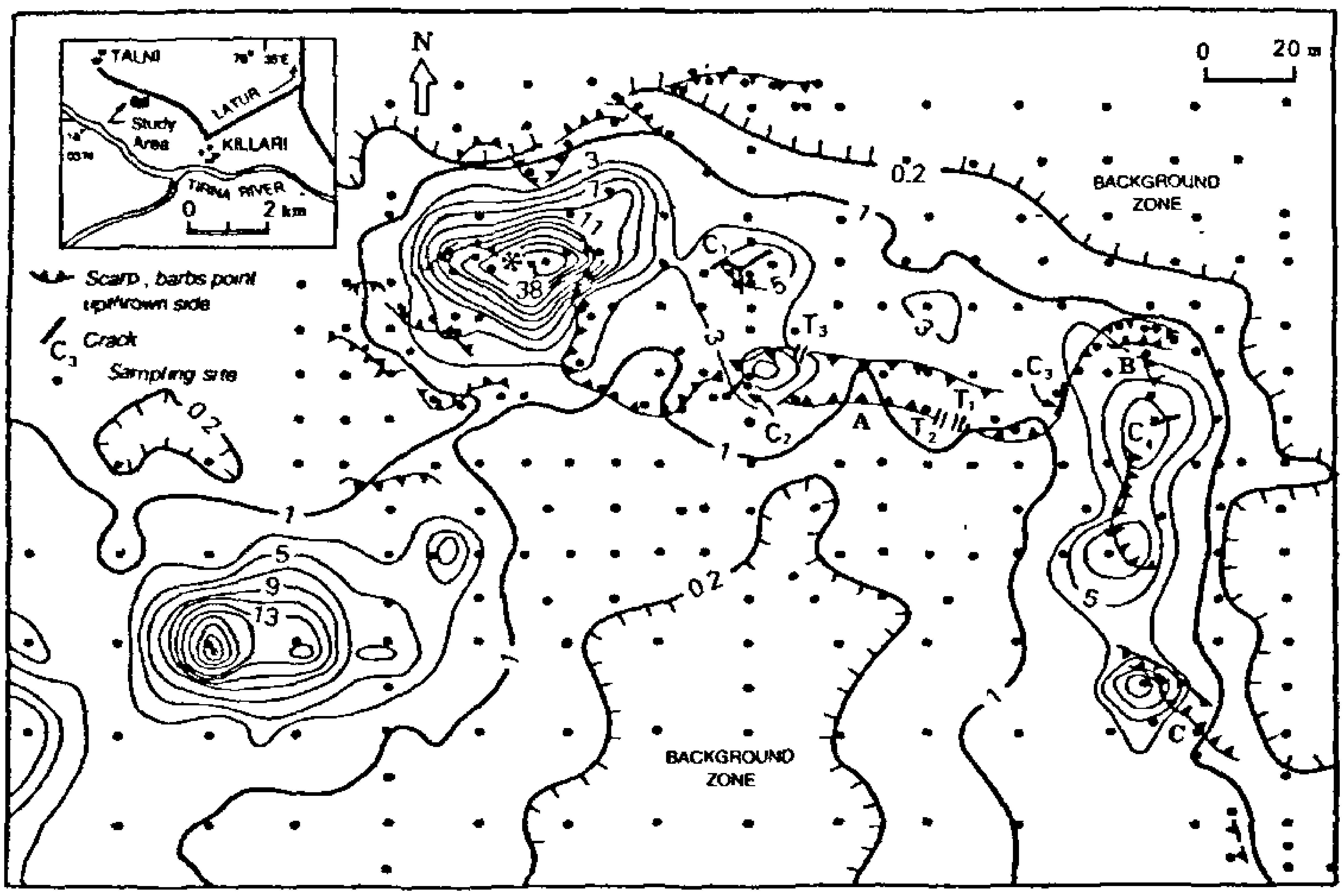

Figure 1. Trace of surface rupture in a 300 × 200 m area and helium results: 'A' is a ridge-like segment with scarp heights of about 15 cm on the northern and 70 cm at the maximum on the southern side. 'B' is a similar but shorter, narrower and arcuate feature with scarp heights of 30 and 15 cm at the northern and southern sides respectively. At 'C' the scarp height is 50 cm near the central portion, decreasing to 15 cm towards the northwestern and southeastern edges. All other scarps are gentler features, some very feeble. A shortening of 0.5 m has been inferred from ground deformation studied in three trenches dug[1] (T_1 ... T_3). C_1 ... C_4 are cracks, 2 to 10 cm wide and 2 to 5 m long. Contour-values are helium in overburden-gas in ppm (after deduction of the atmospheric background).

group of ten documented examples of surface rupture from historic earthquakes in the stable continental regions of the Plate Interiors (SCRs)[8]. An earlier instance in the Indian SCR is the 1819 Kutch earthquake which left a scarp 6 to 9 m high and at least 90 km long. The importance of this feature has been described by Johnston and Kanter[6].

Helium in overburden-gas was analysed with a field-portable and sensitive sniffer[9] with a sensitivity of 0.02 ppm at atmospheric concentration (5.24 ppm) levels. The overburden is a thin veneer (~ 30 cm) of black soil underlain by highly weathered basalt. Overburden-gas was sampled at a depth of 1.5 m.

A helium map of the 300 × 200 m-area, along with the rupture trace in it, is shown in Figure 1 (atmospheric background of 5.24 ppm has been deducted from all helium values). Measurements outside the area bound by Figure 1 showed the 'regional' value to be less than 0.2 ppm. Therefore, sites in Figure 1 with less than 0.2 ppm are considered as constituting a background zone. The major segments of the rupture trace with different orientations are well enclosed inside a pair of 1 ppm-contours (a peak zone), which include highs of far higher magnitude. The remaining part emerges as an intermediate zone (sites with 0.2 to 1.0 ppm). Within the peak zone, contours have been shown at 2 ppm intervals. The highest value recorded at a site is 38 ppm. Sharp highs aligned E-W in the central part and N-S in the eastern part, mark the scarps and the immediate vicinity. A 3-D perspective is shown in Figure 2. Highs also distinguish a southwestern part without any noticeable surface feature. We interpret the peak and intermediate zones as demarcating a deep 'fissure' through which there is excess leakage of helium. We also sampled a number of features – cracks, 'uplifts' and 'subsidences', etc., related to the main event and aftershocks at several distant locations (up to 50 km). No distinct helium excess was found in these places. The helium anomaly shown in Figure 1 therefore seems to be specific to the rupture trace.

To compare our present observations we cite some important overburden-gas helium results in different tectonic settings reported in the literature. Along the fault formed by the 1966 Matsushiro earthquakes–swarm, Wakita and others[10] found 'helium spots' (helium up to 350 ppm). To our knowledge, this seems to be the only published work of helium measurements over surface rupture of an earthquake. $^3He/^4He$ ratio is

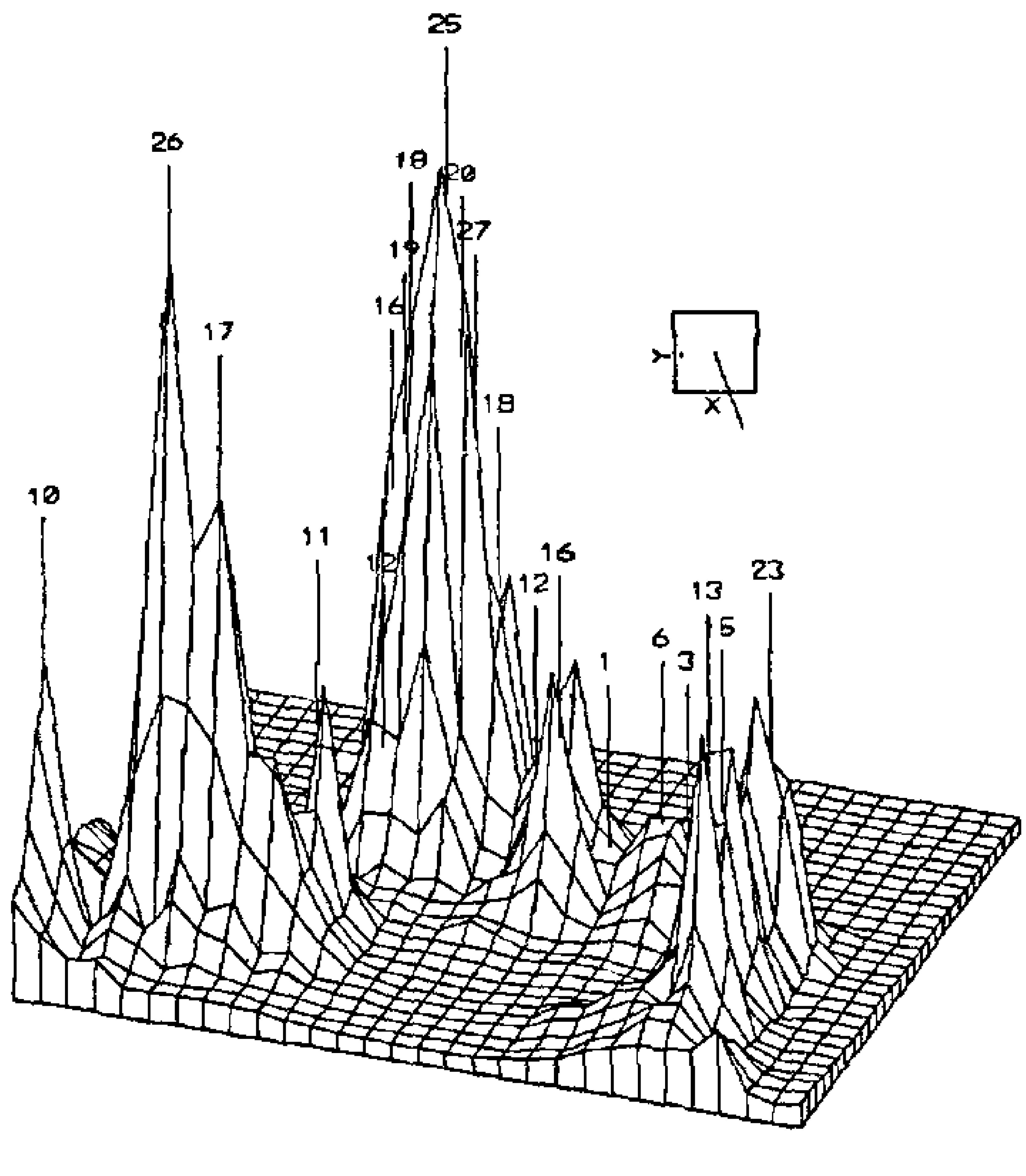

Figure 2. A 3-D perspective of helium results over Figure 1 – area. Numbers indicate peak-values in ppm.

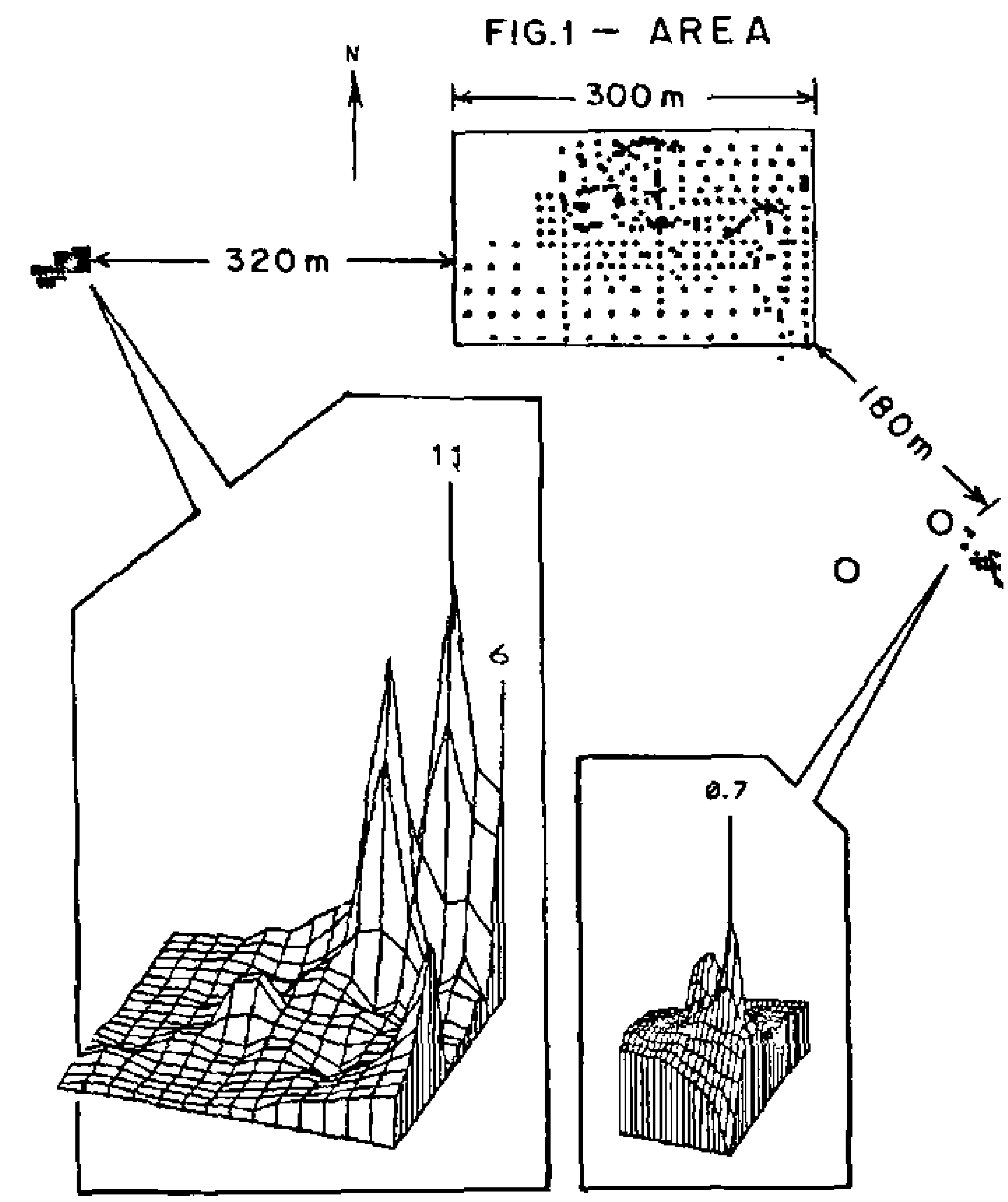

Figure 3. Two small features away from Figure 1 – area and helium results (Numbers indicate peak-values in ppm.) Two bore-holes (open circles), 33 and 70 m deep, went dry immediately following the earthquake. Gas was flowing from them (under some pressure) for a few weeks. This contained up to 103 ppm.

high, characteristic of volcanic gases, and interpretation of these spots and the earthquakes-swarm is in terms of diapiric rise of magma. This setting is vastly different from the present case. Along a small mapped segment of the San Andreas Fault, Jones and Drozd[11] measured 40 to 98 ppm of helium over 30 to 40 m (the highest, at a spot, of 430 ppm). This, however, is a well-known Plate boundary situation. For shallow fault/fracture system(s) in normal areas, helium anomalies reach a few hundred ppb; typical examples are given by Roberts and Roen[12] over a fault segment in Pennsylvania. Many hydrocarbon deposits have significant and a wide range of concentrations of helium, some at commercially viable levels (> 0.3%). The reported overburden-gas anomalies over them, resulting from leakage via migration pathways, vary widely from a fraction of a ppm to about ten ppm[13–14].

The location of the present study lies over < 500 m-thick Deccan Traps which is underlain by Precambrian crust. The helium emanation over the peak zone (Figure 1) is exceptionally high for a normal fault/fracture system in such a setting and is to be linked only to the faulting associated with the earthquake. The surface rupture is believed to extend beyond the area shown in Figure 1. The area bound by Figure 1 is devoid of agricultural cultivation, a condition which permits recognition of even feeble features. But in the adjacent lands, which are under cultivation, many small features may be concealed or obliterated by rains in the weeks following the earthquake. Two small upwarp-like features, 320 m west and 180 m southeast were, however, brought to our notice and Figure 3 gives a 3D perspective of the results obtained over them. Helium highs also mark these features. In the western feature, 11 ppm-helium has been observed at one site. The two features point to lateral continuations of the surface rupture. Work is in progress to locate such 'high spots' which could help in mapping the intersection of the earthquake fault with the surface.

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Action potential – A possible signal in root to shoot communication caused by water deficit around roots of sunflower seedling

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Exposure of sunflower roots to polyethylene glycol (PEG-6000) induced osmotic stress caused a rapid depolarization of surface electrical potential at the shoot apex within 25 seconds. It was found that while the leaf water potential and the osmotic potential in control seedlings showed no variation during the entire period of experimentation, the leaf water potential in polyethylene glycol treated seedlings started decreasing after 2 min of treatment without any marked change in the osmotic potential. Similarly, the stomatal resistance in control seedlings remained constant during the course of experimentation but the polyethylene glycol treatment affected the stomatal resistance within 30 seconds and it continued to increase 3 min after the treatment. All these events occur in a time scale of seconds to minutes and in a sequence. It is concluded that the action potential acts as a signal in root-to-shoot communication under osmotic stress.

PLANTS regulate their metabolic processes and morphology when growing in drying soil by reducing the size of the plant, leaves, etc. However, with the exception of extreme drought, the annuals do complete their life cycle. In wheat cultivars and *Triticum* species grown across a line source irrigation system on a deep alluvium with a charged moisture profile at planting, very small differences in water potential (ranging -0.2 to -0.3 MPa) were observed between the maximum irrigated and non-irrigated plants, though differences in growth among them were enormous[1]. On the basis of various experiments, Gowing *et al.*[2], Passioura[3], and Passioura and Munns[4] suggested the occurrence of a root signal which regulates initiation of leaf growth, stomatal resistance, etc. despite no change in water potential. Based on several experiments, it was envisaged that the effects of soil drying on signalling between root and shoot must be primarily of a positive nature, i.e. an increase in the supply of some physiologically active substance[5]. Analysis of the composition of xylem sap from unwatered plants showed a decline in the concentrations of most components except the concentration of ABA, which increases substantially following soil drying[6]. However, the central role of ABA as a root sourced signal has been challenged[7], and an unknown substance was implicated in root-to-shoot communication under soil water deficit. We demonstrate here that in the sunflower seedling an action potential acts as a signal in root-to-shoot communication during PEG induced osmotic stress.

Sunflower (*Helianthus annus* L. cv. RHA 274) seedlings were grown in sand culture in a net house at the ambient sunlight, temperature and humidity for one

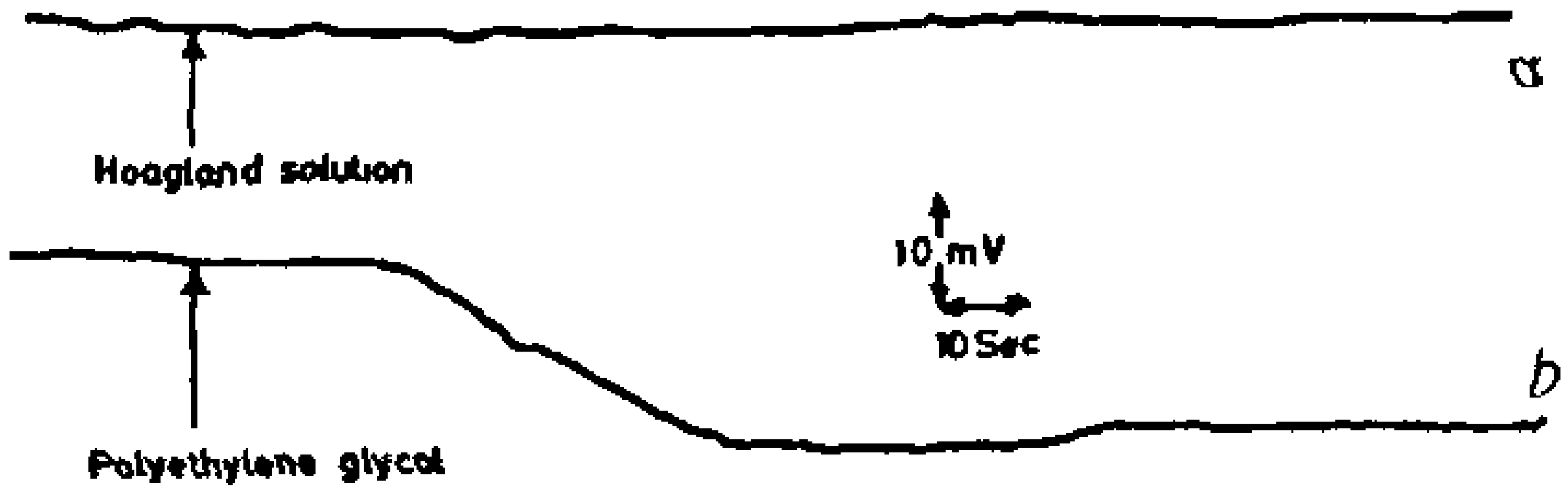

Figure 1. Effect of osmotic stress on surface electrical potential at the shoot apex of sunflower seedling Methods to create osmotic stress and to measure surface electrical potential have been described in the text *a* = pattern of electrical potential in control, *b* = pattern of electrical potential in response to osmotic stress