The threatened tufaceous site of Sahasradhara, Dehra Dun, U.P.

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The paper deals with the present threatened condition of the tufaceous site of Sahasradhara, a well known picnic spot in Dehra Dun District of north-western Uttar Pradesh. The site was a natural repository of an especialized shade-tolerant flora with an array of wide ranging calcicolous forms.

Previously, active tufa formation was taking place because of the precipitation of dissolved calcium carbonate in the spring water. Now it has gradually been disturbed due to heavy human encroachment in this delicate biocoenose. The natural setting has already been disfigured and the floral diversity is reduced to a minimum. Unfortunately, no efforts have been made to protect this tufaceous biocoenose and its whole interesting vegetational mosaic.

Key-words- Vegetation, tufaceous site, Sahasradhara, Dehra Dun.

INTRODUCTION

The northwesterly district of Dehra Dun in Uttar Pradesh extends over an area of 3088 sq km. "Of no other district in India can be truly said that the names of the boundaries are better known than the name of the district itself" (Baker, 1886, quoted by Walton, 1911). The irregular parallelogram-shaped Dun valley - a unique microgeomorphic unit, is bounded on the north by the Mussoorie range of the Himalaya in "an immense amphitheatre", the sub-Himalayan (Siwalik) ranges on the south, the river Ganges on the east and the river Jamuna on the west. A characteristic feature of the Siwaliks shows itself in the form of a number of longitudinal spindle-shaped valleys, known as Duns (Pascoe, 1950). Dehra Dun was once the most picturesque and well wooded of sub-Himalayan Duns. The perennial streams nourished a fresh and luxuriant vegetation and the hills gave an exquisite variety to the landscape (Walton, 1911). Over the years, much of the enchanting landscape has disappeared. The valley faces an acute water shortage. Lumbering, unplanned urbanization and chaotic vehicular traffic- all have engraved ugly marks on the serene visage of Dehra Dun.

Sahasradhara, the well known picnic spot in eastern Dun has also lost much of its original vegetation and beauty.

STUDY AREA

Sahasradhara, situated about 14 km from the town of Dehra Dun lies between (30° : 23' N and 78° : 8' E) at an altitude of 600 - 1600 m above sea-level at a place where the river Baldi descends the steep hills of Mussoorie and enters the wide valley of Dehra Dun. Besides the river Baldi, there were many other streams and rivulets contributing to the scenery of this area. Some of them have dried up. Sahasradhara or the "thousand-fold spring" is the name given to a series of stalactitic caves and caverns over which water drips from the roofs in a perpetual shower at the precipitous right bank of the Baldi River in a village called Bagda Dhoran, east of Rajpur (Walton, 1911).

GEOLOGY

Krol formation contributes to the topography of caves and travertine deposits at Sahasradhara. It consists of slaggy limes and shales with relatively massive limestone beds near the Sahasradhara falls. This massive limestone-dolomite band is overlain, just near the spring, by a series of limestone, shales and dolomites (courtesy, Directorate of Geology and Mining, U.P.). The topography formed by Krols at Sahasradhara with numerous hollows and caverns is reminiscent of karst areas becaouse of the existence of certain conditions which are generally considered to be essential for the development of Karst. These are : (1) the presence of a soluble rock-limestone; (2) the dense, highly jointed limestone that would allow permeability by numerous joints and bedding planes but not mass permeability and; (3) abundant rainfall.

TUFA/TRAVERTINE DEPOSITION AT SAHASRADHARA

The sight of travertine deposition at Sahasradhara is prominent enough to attract the attention of any passing pedestrian who turns his gaze towards the green hillside on the right bank of river Baldi, opposite the rest house and sulphur spring. The usual way of approach was once a small suspension bridge across the river Baldi but now a solid sturcture has been made. The bridge ends at the steps of a temple. The temple once nestled in charming natural surroundings bas been transformed into an ugly, garish structure "beautified" very recently ! As one proceeds towards right, the precipitous hillside, overarched by a huge 'dome-shaped' area, comes into full view. The solubility of limestone has resulted in the formation of the cavernous hillside (P1.1, fig. 1). The stream water after passing underground for some distance cascades down the entire cliff and over the caves in sprays, drips down the floor of the latter and on evaporation deposits calcite in the form of stalactites, stalagmites and tufas* or travertine around the calcicolous

vegetation. The precipitous and tufaceous hillside strewn with boulders, cliffs and intercepted with "travertine cascades" had till recently a continuous cover of algae, bryophytes, herbs, shurbs and a sprinkling of trees. (Pl.1., figs 1-6; P1. 2, figs 1-7).

PICTUREQUE GLORY OF YESTERYEARS

The prominent scenery of the area caught the attention of many distinguished naturalists in the past. As early as 1839, Royle's famous book "Illustrations of the Botany and other branches of the Natural history of the Himalayan mountains and the flora of Cashmere," Vol.1. p.33, mentioned that "the sulphurous spring in the vicinity of Suhansudhara with the dripping rocks and numerous stalactites hanging down from the rocks of the cavernous limestone, with the leaves etc. encrusted with carbonate of lime have often attracted the attention of, and has been described by travellers...."

Williams (1874) in his historical and statistical memoir of Dehra Dun described Sahasradhara as follows:-

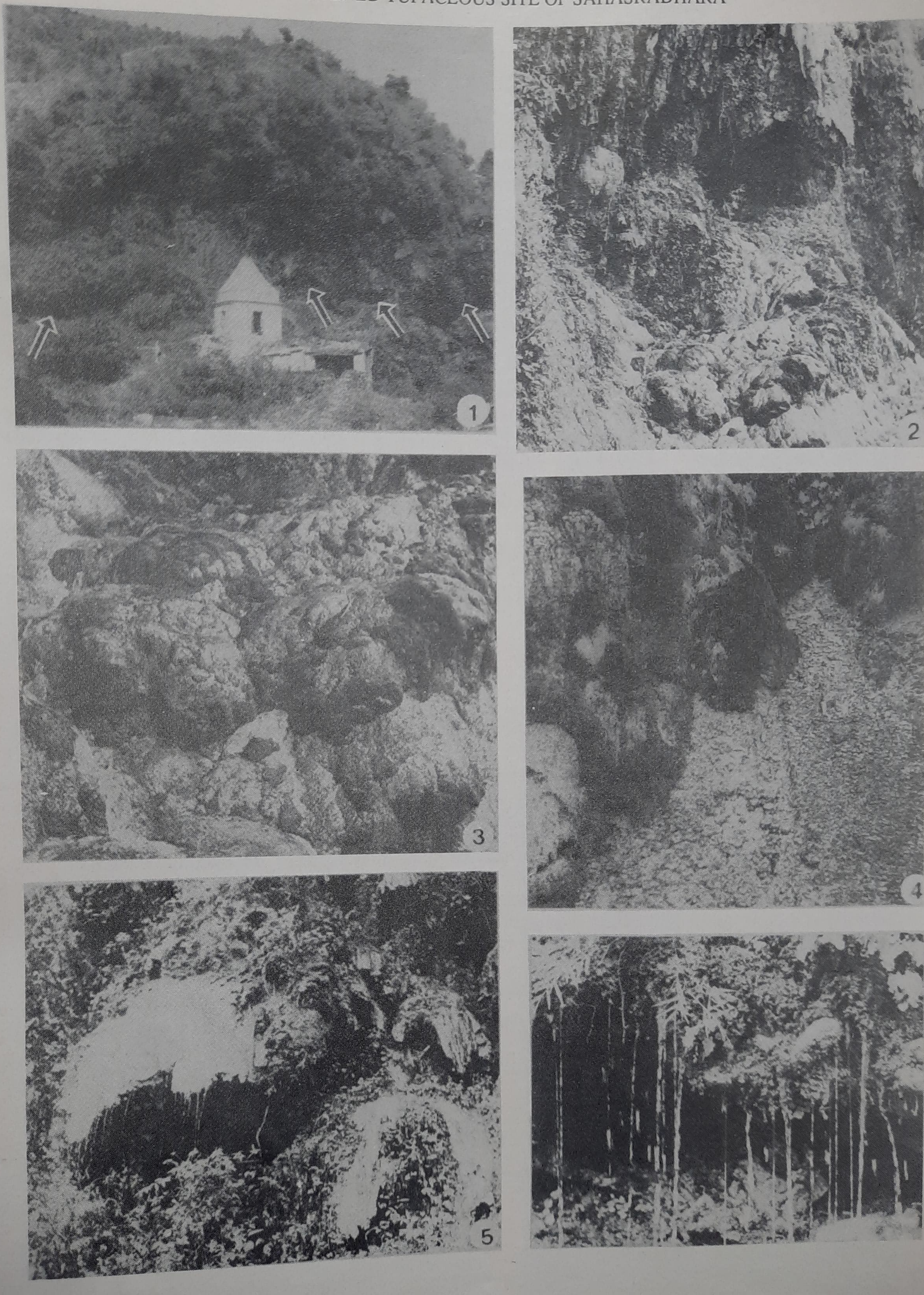
"The only other holy spot worthy of special notice is the Suhusra Dhara, the place of the Thousand Drippings which a very simple phenomenon has invested with peculiar sanctity in the eyes of the people. From the side of a charming valley to the east of Rajpore, oozes a mountain stream, distilling its waters over a precipice thirty feet high, and leaving a crust of lime on everything it touches. Particles thus accumulating for centuries, have made a projecting ledge forming a sort of cave, from the roof of which falls a perpetual rain that turns every glade of grass coming in contact with it into a petrification. From above hang stalactites innumerable. Stalagmite covers the ground beneath. In a smaller cave of similar formation, lies a lump of stalagmite not unlike the popular figure of the Maha Deo (the Lingum). Opposite, there is a sulphur spring also possessing powers of petrifaction."

* **Calcareous tufa,** a soft porous limestone, is formed through precipitation of the dissolved mineral matter calcite from the supersaturated waters of rivers, springs, or lakes and deposited as layers preferably around algal or bryophytic 'frame works' or moulds. The plants become incrusted by the deposit. They eventually die but leave their original structure imprinted on the material. With the passage of time this fragile form hardens into non-porous concretionary variety of calcium carbonate called travertine.

He also quoted from the Delhi Gazette (1868)-"In the commencement of this day's march, we enjoyed a sight of uncommon beauty, which was rendered more striking by being concealed by a jutting point of rock till we approached very near and ascended a little bank, when it suddenly burst on our view. It was a fall of water from an excavated bank with a cave or grotto at each extremity, forming together an arch of about 100 feet in perpendicular

PLATE 1

1. View, showing the top of the 'dome' at the tufaceous site of Sahasradhara. The caves appear as dark patches in the cavernous hillside. (arrows).
2. Mouth of a cave (arrow) and underlying slope of the tufaceous hillside. Overhanging masses of tufa are seen above the mouth of the cave.
3. Close-up of the slope showing 'steps'made up of hard, incrusting " Petalonema-rock" formed by black cushions of *Petalonema alatum* Berk. var. *indicum*. Rao (pure patches).
4. *Petalonema-Hydrogonium* algal-moss association on calc-tufa. The darker patches above, represent dense moss polsters of *Hydrogonium gracilentum* (Mitt.) Chen and the lighter area towards base is formed by solid incrustations around *Petalonema*.
5. A "travertine-cascade" at Sahasradhara. Photograph shows water trickling down a fan-shaped mass of calc-tufa (white patch) in centre. On the right hand side is another **"cascade-tufa"** calcium deposition taking place over moss *(Hydrogonium gracilentum)*.
6. Exposed, "hanging"roots of *Eupatorium adenophorum* Spreng. incrusted with an algal-felt and calc-tufa along which the calcareous stream water trickles.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height, with a substended base of 80 or 100 yards. Through every part of the impending summit the water oozed out in drops, which fell in showers into a basin, whence it was carried by a small stream into the river below. The lofty trees and luxuriant shrubs which overhung the brow threw a partial shade over the cascade, was reflected in the sparkling globules, giving a richness and brilliancy to the scene, which words are incompetent to express. Upon an inspection of the grotto to the right, we were struck with new and more singular appearances. It is a cavern, about six feet in height, ten in depth and fourteen or sixteen in length, and is a natural excavation, the walls and roof of which are rocks. The water filters through the top, from which pandant shoots like icicles are disposed in all the different stages of petrifaction : the small ramifications form variegated beds of moss serving as conductors for the water when it first begins to crystallize; and from a tube or pipe, they become, by repeated incrustations, a firm consolidated mass. The various colors produced by the vegetation and changing with the different shades of light, give to the outer surface the appearance of mother o'pearl; but when the petrifaction is complete, the inside has a great resemblance to alabaster."

Over the years, this charming limestone setting dressed with a calcicolous flora went on gradually losing its variety and grandeur and the scenario is much disturbed today.

THE TUFACEOUS VEGETATION OF SAHASRADHARA

The tufa-building vegetation of Sahasradhara was studied by the author during 1970-74 (See Text-fig.1). At that time, active tufa formation was taking place on all moss-covered cliffs, on cascades and their edges and over the entire talus slope of the fall in the middle and lowermost parts of the massive dome-shaped limestone area. The scarped cliffs and the precipitous sides were festooned with huge masses of tufa, hanging like curtains. (Pl. 1, figs 2-6; Pl.2, figs 1,6). The calcium deposition occurred specially around tufts of mosses, though the trickling water seemed to petrify nearly all vegetational matter that came in contact with it (Pl.1, figs 3,6' Pl.2, fig. 1,3,6, Pl.3' figs 2-7). The tufaceous vegetation including the primarily associated plants, like algae (Pl.1, fig.3; Pl.4, figs 1-6; Pl.5, figs 1-7) and bryophytes (Pl. 1, fig. 4; Pl.2, figs 3,4; Pl.3, figs 1,2,3,5,6,7) and the secondarily associated plants, like pteridophutes and angiosperms (Pl.1, fig 6; Pl.2, fig 7), the mechanism of tufa-formation, succession at the tufaceous site were studied in detail (Pant, 1974, 1987;Parihar & Pant, 1982).

Among the close associates of tufaceous bryophytes were many cyanobacterial forms like *Chroococcus, Merismopedia, Nostoc, Petalonema* intermingled with many diatoms (*Gomphonema* sp., *Nitzschia* sp. *Tabellaria* sp.) and a desmid (*Cosmarium* sp.) [Pl. 4, figs 1-6; Pl. 5, figs 1-7].

THE BIOLOGY OF TUFA

Mosses are often the most conspicuous plants of tufa deposits where they provide a suitable environment for the precipitation of large quantities of calcium carbonate. Their great regeneration potential makes them successful in calcareous biocoenoses, perpetuates the process of tufa-formation, gives them an advantage over dead bits of vegetational debris and other vascular plants. The tufaceous bryophytes are interesting in being able to modify or change their landscape considerably as they go on building a biogenic rock (calc-tufa or travertine) [Pl. 2, figs 1,2,5; Pl.3, fig. 4]. Rippled travertine draperies, "travertine cascades", conical outgrowths, stalactites and stalagmites with "dripping points" are mainly built around bryo-vegetation. (Pl.1, figs 2,5,6; Pl.2, figs 1,2,6). They serve as fragile "frame works" or moulds/nuclei around which layers of calcite are accumulated. This biofactor gives them a porous, reeflike mammilated appearance or an impression of "heaps of mosses turned into stones" (Pl. 2, figs 1,3,6; Pl. 3, figs 3,4,5,6,). This is a dynamic process with the older parts and rhizoidal mass getting buried or 'cemented' below the calcareous ooze/mud/sediment while younger, green shoots regenerate above at apices (Pl.2, fig. 3; Pl.3, figs 2,7). Together with bryophytes, other plant groups like ferns and angiosperms, cyanobacteria (mostly)

PLATE 2

1. Interior of a tufaceous cave. Moss-associated solid accretions of calcite on cave ceiling.
2. Stalactites hanging from the roof of a cave.
3. Tufa-incrusted leafless axis of *Vesicularia montagnei* (Bel.) Broth, appearing like a cylinder and a few lime incrusted thinner leafy branches towards its base, x 3.
4. An extracted leaf of *Vesicularia montagnei* from the subfossil assemblages - the chief colonizer of cave interiors, x 86.
5. Thin section of porous, brittle tufa showing a spherical oolite formed by deposition of calcium carbonate in concentric layers around a central nucleus. The oolite shows growth of calcite crystals, x 150.
6. Water dripping down a moss-covered tufaceous mass in the spray zone, Sahasradhra (arrow). hanging masses of calc-tufa in background.
7. An orchid, *Epipactis veratrifolia* Boiss. growing over a moss-covered tufa deposit.

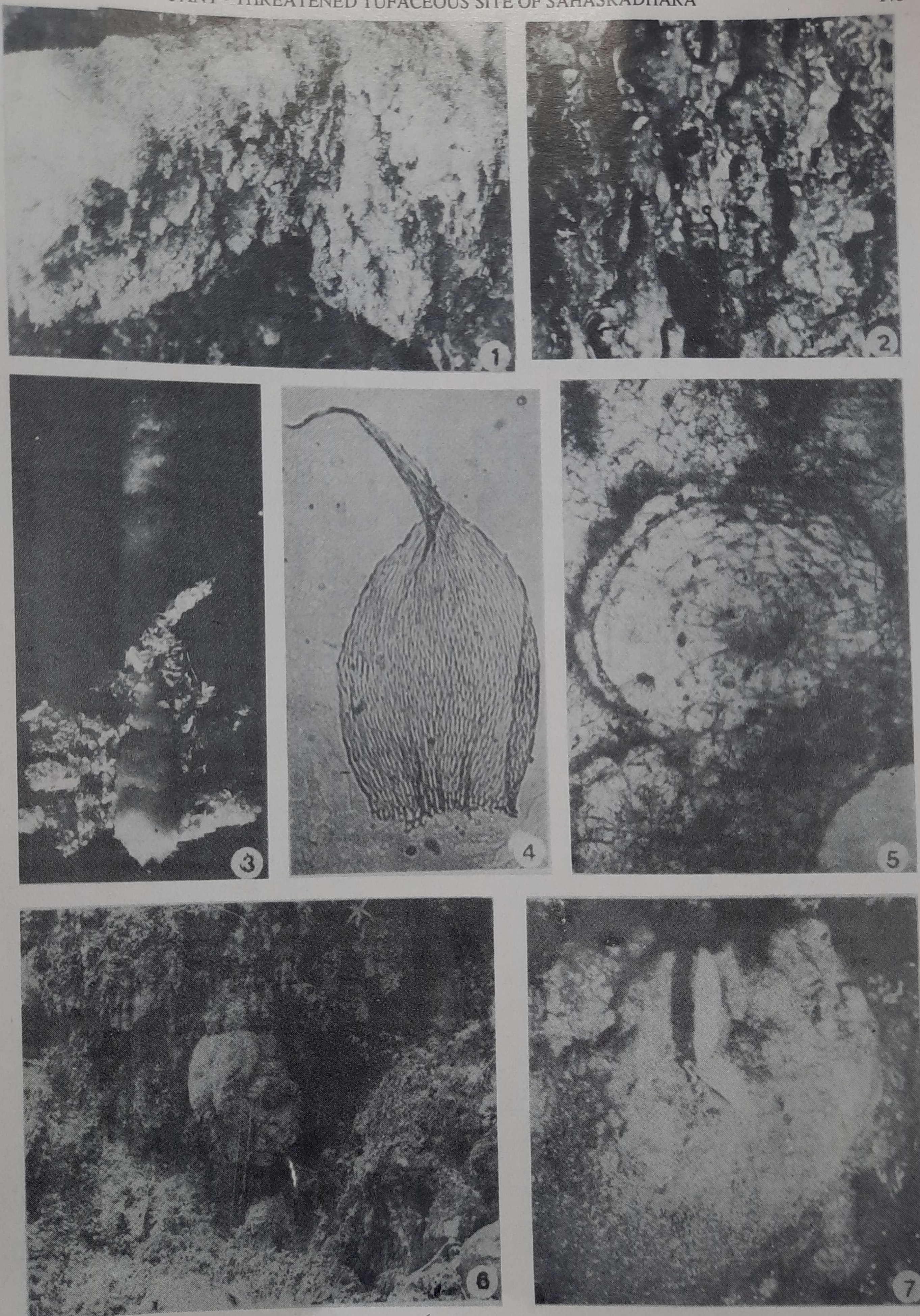

PLATE 2

and some chlorophyta are also involved in and incorporated into tufa. The resulting tufa fabric is often highly porous, but with the passage of time it turns into hard travertine. The "petrified" structures were aptly termed as "bryoliths" by Boros (1925).

Cyanobacterial calcification is primarily due to the extracellular nucleation of crystals of calcium carbonate within and upon the polysaccharide sheath. The sheath appears to provide sites favourable for calcification. Nucleation of calcium carbonate crystals may occur within the sheath(impregnation) and upon it (encrustation). In addition, the sheath can trap sediment particles which are then bound into the cyanobacterial mat as growth continues.

Trapping and binding of particulate sediment is a separate process which alone,or together with calcification, is responsible for stromatolite formation. Several cyanobacterial taxa exhibit specificity for calcification but none is known to be an obligate calcifer. Encrustation depends, in part, upon specific biological properties of associated organisms. To a great extent, however, it depends on environmental influences originating from the immediate micro-environment as well as the environment at large, with its overall biogeochemical properties.

The mineralogy and composition of cyanobacterial calcium carbonate are consistent with that expected to form inorganic precipitation from the surrounding water (Golubic' 1973; Pentecost & Riding, 1986).

Many inorganic processes could also give rise to formation of tufa. Recent studies suggest that plants play an important physical rather than chemical role in tufa formation. However, the complex interrelationships between accreting material and the associated organisms, many of which become cemented into the rock, are little understood. Tufa deposition can result from several unrelated changes occurring in the percolating water. The major change is thought to be the diffusional loss of carbon dioxide to the atmosphere. There is also evidence to suggest that the uptake of carbon dioxide by plants, temperature changes and water loss by evaporation play some part in tufa deposition. (Emig, 1917, 1918a, b, 1921; Wilson & Guest, 1961; Pentecost & Lord, 1988).

TUFA DEPOSITS-THEIR USE AND CONSERVATION

Tufa is a potentially valuable source of vegetational history. Such deposits are distributed all over the world. They are Pleistocene, Post Pleistocene (Quaternary) or Recent in age with fluviatile, lacustrine or glacial origin. To understand the conditions under which calc-tufas were formed in the past climates, a knowledge of the associated flora is necessary. The sites may have a potential value as sources of palaeoenvironmental data and as a medium for the preservation of archaeological material (Pentecost & Lord, 1988). The porous rock has been used as a building and ornamental stone since antiquity. The Romans used it in the construction of their colloseum. It was widely employed in English garden rockeries and other buildings throughout Britain. The more elegant American banks were also decorated with travertine floors and staircases' not very long ago (Seward, 1944; Crum, 1976; Pentecost 1981).

Although the basic mechanism of tufa deposition is known, much more is needed to be understood regarding the rate of deposition as a function of prevailing climate. Calc-tufas are formed in a wide range of climates today all over the world yet depositional rates of tufa are obtained from a few sites, mainly in U.K. and Germany (Pentecost, 1987; Pentecost & Lord, 1988). We know little about Indian calc-tufas and no experimental work has been done on the rates of its deposition. It is rather unfortunate that instead of encouraging to "continue research into the genesis and biology of this remarkable material", this well known and accessible site is being destroyed. One can see many scars left by the monstrosities of urbanisation through the years. Scarcity of water in the area due to drying up of many streams and rivulets - their pollution, biotic disturbances like cutting and falling of trees and woody shrubs, and subsequent loss of top soil, damage due to regular trampling and dynamiting - all have contributed to the bit by bit disfiguration of the faultless natural picture. The grotto, the caves, the algae-moss associated stalactites and stalagmites - all combined to give an aura of elegance to the once celebrated tufaceous falls but today the entire cavernous hillside and the spray zone lie in a state of wreckage. Due to heavy human encroachment in this delicate biocoenose, it seems that water may stop dripping altogether. A dry xerophytic vegetation may succeed the sciophilous flora.

In recent years, much has been said and written about Sahasradhara - its disturbed ecology due to limestone quarrying, deposition of dust on plant surfaces, inhalation of dust and gases emitted from the kilns and illicit felling of trees. However, inspite of all this hue and cry, practically

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PLATE 3

Various stages of incrustation, Sahasradhara specimens.

1. A fresh unicrusted cushion of *Bryum cellulare* Hook., natural size.
2. Plants of *Hydrogonium gracilentum* partly incrusted with calcite coating. Apical portions of shoots are still live and regenerating.
3. 'Frame-work' of mosses around which tufa has accumulated according to the phyllotaxy of leaves. Tufa-fabric is around *H. gracilentum*, x 4.
4. A lump of tufa cut longitudinally to show the hollow cavities and the position of an embedded moss shoot (arrow), natural size.
5. Three incrusted shoots of *Chiloscyphus polyanthus* (L.) Corda, separated from the tufaceous mass, x 3.
6. Tufa-incrusted shoots of *C. polyanthus*, x 3
7. A shoot of *Hydrogonium gracilentum* covered witha thick deposition of calcite below, but the leaves at the apex are regenerating, x 6.

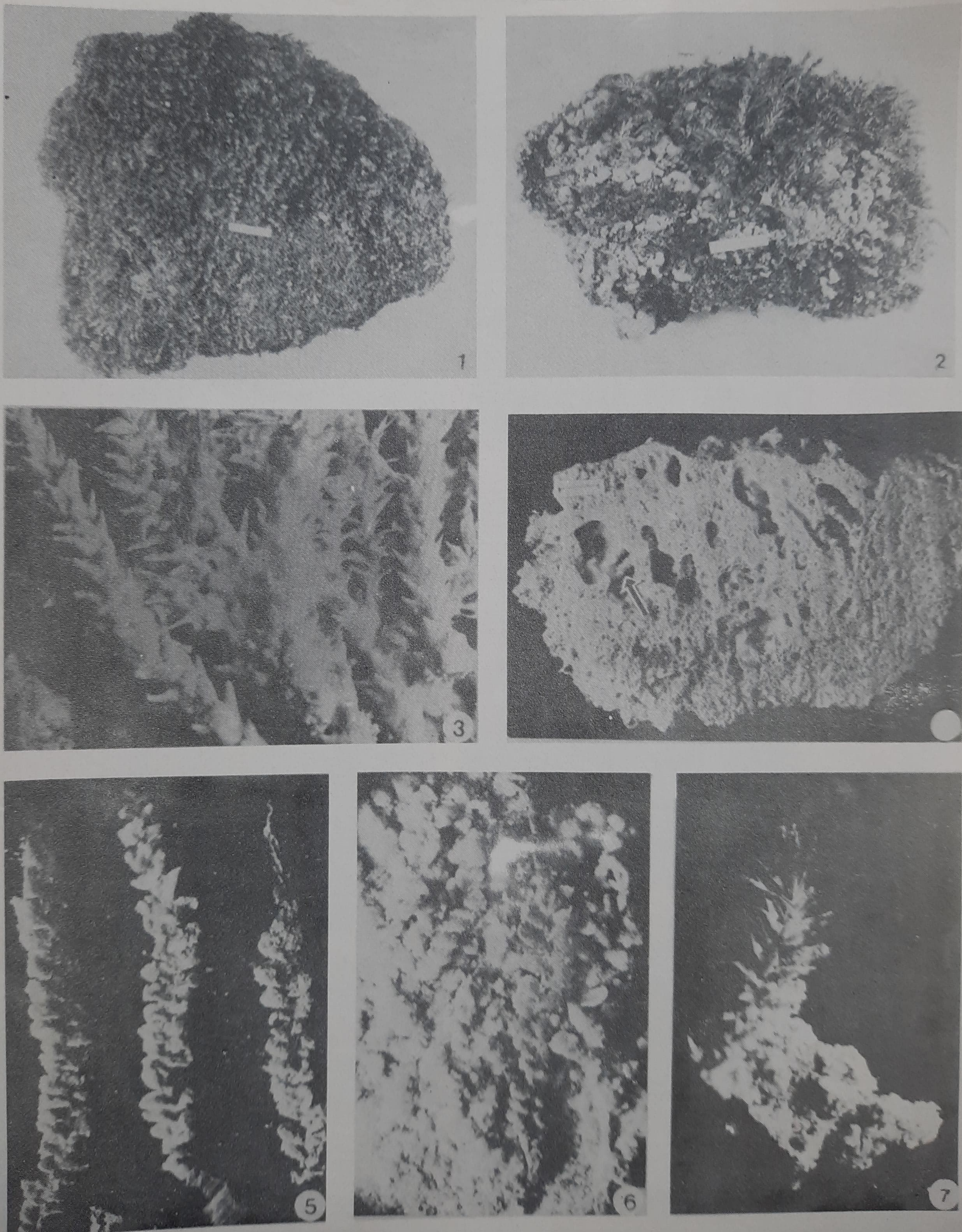
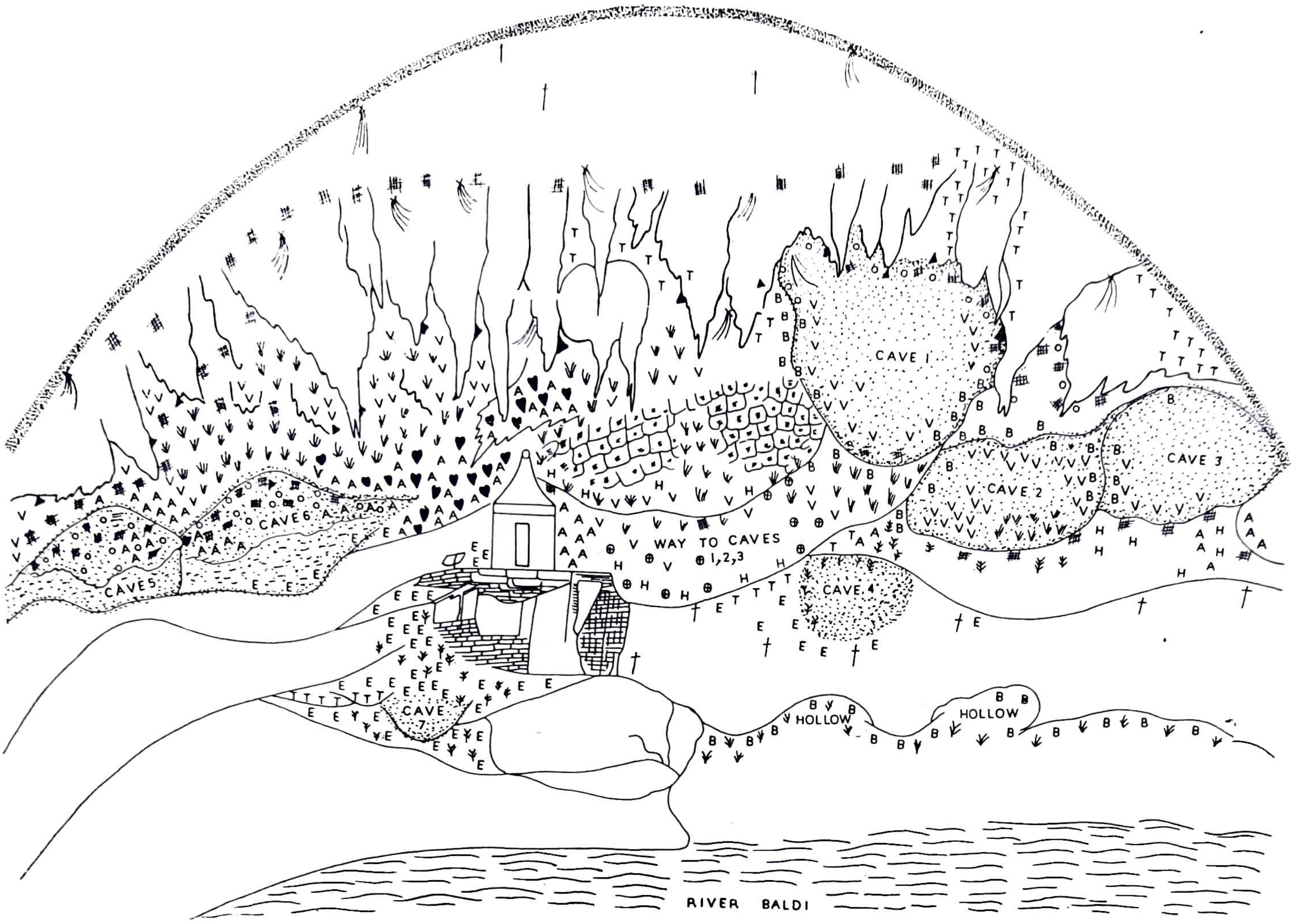


PLATE 3



Text-figure 1. Diagrammatic sketch of the main travertine site at Sahasradhara of early seventies showing the 'dome' shaped hill, caves, hollows and river Baldi. The distribution of hanging masses of tufa and the main tufa-building plants and assoications are indicated by the following signs. The picture is much disturbed today.

- Hanging masses of tufa
- ⊕ *Cladophora glomerata* (L.) Kuetzing
- *Petalonema alatum* Berk. var. *indicum* Rao
- *Hydrogonium gracilentum* (Mitt.) Chem.
- B *Bryum cellulare* Hook.
- V *Vesicularia montagnei* (Bel.). Broth.
- C *Cratoneuron commutatum* (Hedw.) Roth.
- A *Adiantum capillus-veneris* Linn.
- *Pteris cretica* Linn.
- *Colocasia esculenta* Schott
- ▲ *Epipactis veratrifolia* Boiss.
- E *Eupatorium adenophorum* Spreng.
- H *Hypericum oblongifolium* Choisy
- *Itea nutans* Royle
- *Phoenix humilis* Royle
- *Pogonatherum paniceum* (Lamk.) Hack.
- O *Primula floribunda* Wall.
- T *Thysanolaena maxima* (Roxb.) O.Ktze.
- Tufaceous floor of caves 5 and 6 covered with *Hydrogonium - Bryum - Vesicularia - Chiloscyphus Pellia - Adiantum - primula association.*

PLATE 4

1. *Petalonema alatum var. indicum*. Habit.
2. A fan-shaped cushion of *P. alatum* var. *indicum* heavily impregnated with tufa, cut lengthwise to show the zonations of growth. Filaments are arranged more or less radially upwards, x 4.
3. Trichome of *P. alatum* var. *indicum* showing trumpetshaped tip and thick, stratified divergent sheath, x 600.
4. A *Nostoc* colony surrounded by a firm boundary of sheath extracted form the tufaceous residue, x 230.
5. A colony of *Chroococcus* sp. isolated from tufa, x 720.
6. *Chroococcus* sp., a two-celled colony from tufa, x 1000.

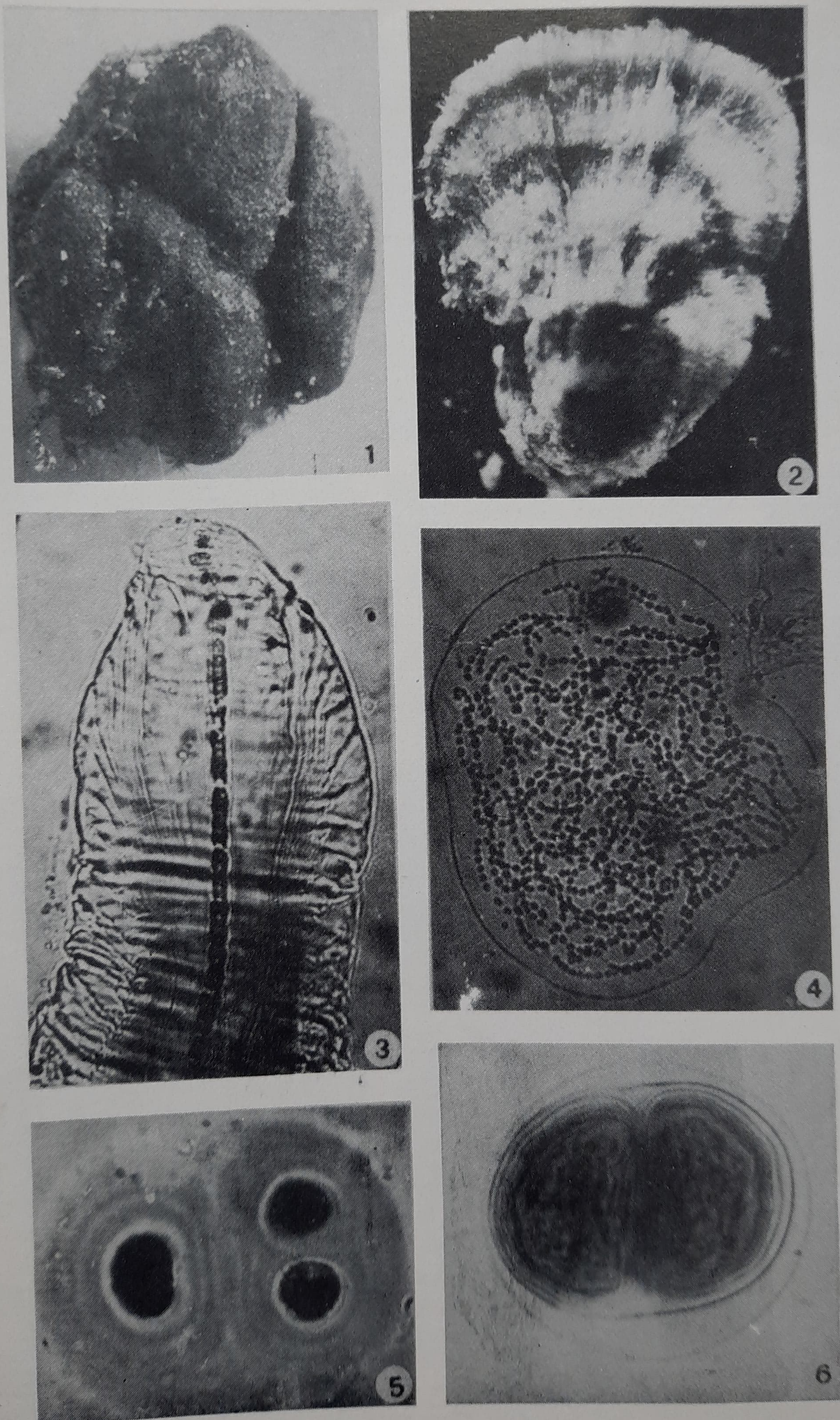


PLATE 4

nothing has been done to conserve and protect the tufa falls, the especialized tufaceous biotope with its topography as well as edaphic and microclimatic factors which allow onl, a few, specially adapted trees and the accompanying shade-loving vegetation to thrive. Consequently, the site with its whole vegetational mosaic is heavily disturbed. The plant species are fast disappearing and the floral diversity has already been reduced to a minimum. At the same time, the process of tufa formation is also inhibited to some extent.

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PLATE 5

1. Tabular colony of *Merismopedia* sp. with cells regularly arranged in a single layer in groups of four, x 2000.
2. Diatoms from tufa. *Gomphonema* sp., x 680.
3. *Nitzschia* sp. (single elongated diatom) and *Gomphonema* sp. (a number of smaller diatoms), x 800.
4. *Tabellaria* sp. (single elongated diatom) and *Gomphonema* sp. (a number of smaller diatoms), x 800.
5. *Pinnularia* sp. from tufa, x 800.
6. Two *Cosmarium* cells from tufaceous algal felt, x 1000.
7. Clump of *Tabellaria* sp. , x 500.

PLATE 5