effects or even dominance. Inheritance pattern of secondary metabolites is always complex due to the involvement of many allelic and non-allelic genes. Nevertheless, the point worth making about the present results is that, the genic male sterility offers tremendous scope for qualitative and quantitative improvement of A. paniculata through intervarietal hybridization.

Examples abound where the heterozygote advantage of F₁ progeny due to single recessive genic male sterility has been exploited commercially for improvement in the productivity of a variety of crops, i.e., cereals, legumes, oil seed crops, etc. Contrary to this, there seems to be too little studies and scarce published data regarding the applied and basic aspects of male sterility in medicinal plants. The male sterile lines at present constitute an important genetic resource in our germplasm repository. It throws a fresh perspective for metabolic engineering by changing the combinations of genotypic lines with different range of bioactive andrographolide constituents to fulfill the shifting demands of market. We now tend to assess the combining ability of diverse genotypes with the sterile lines. Literature survey shows that ours is possibly the first demonstration of induced genic male sterility and its significance in genus Andrographis and probably also the first in family Acanthaceae.


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Discovery of nannofossils in a plant bed of the Bhuj Member, Kutch and its significance

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The world-famous Mesozoic rocks of Kutch exposed in the western sector of India have been originally classified into the Patcham, Charli, Kariol and Umia formations in ascending order along with a later scheme of Jhuri, Jhumara, Jhuran and Bhuj formations. Ammonites are the best for dating marine Mesozoic succession the world over. The Kutch Mesozoic succession has been well dated through ammonoids but for its youngest ammonoid-devoid Bhuj Member, of Umia Formation, which is otherwise essentially made up of thick, bioturbated, coarse-grained sandstone and grits with enrichment of iron at places and leaf-bearing carbonate shales at partings. No other marine body fossils are known in the Bhuj Member but for disputed foraminifers. The Bhuj Member had been for long considered a continental or freshwater deposit by several workers. This view was contested by later workers on the basis of the presence of probe and thick ferruginous bioturbated horizons, facies analysis, etc. However, in the absence of datable marine

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body fossils it has not been possible to give precise age to the Bhuj Member.

The present record of datable calcareous nanofossils represented by 32 species from greyish-black shales included in the otherwise profusely burrowed and leaf fossil-rich part of the sand-dominated Bhuj Member, is a chance discovery. The assemblage, though moderately preserved and of low diversity, provides precise age for this unit as early Middle Albian belonging to the CC8 Prediscoeca phera columnata zone of Perch-Nielsen (1985) and/or to NC8 Tranolithus orionatus total range zone of Bown et al (1998). This nanofossil-based age agrees with that earlier suggested indirectly from ammonoid control below and radiometric control above. A shallow, near-shore and warm-water environment of deposition is deduced for the nanofossil-yielding sediment interval of the Bhuj Member, which farther up is disconformably overlain by Deccan Traps. The present study thus supports an uninterrupted exposed marine succession from at least Late Bajocian to early Middle Albian in the Kutch basin.

Keywords: Ammonites, Bhuj Member, Kutch basin, nanofossils, Mesozoic rocks.

The Kutch basin is a pericratonic east-west striking embayment between Nagar Parker (West Pakistan) and Kathiawar uplifts, which opens out and deepens westward towards the Arabian Sea (Figure 1). The six major EW-oriented uplifts are the Mainland, Patcham, Khadir, Bela, Chorar and Wagad highlands which expose the Mesozoic rocks. The classical rock-stratigraphic classification followed herein is the Patcham, Chari, Katrol and Umia while a new scheme has been later proposed as Jurio, Jamura, Jurun and Bhuj formations based on detailed mapping. The sedimentary succession of Kutch comprises sediments in age from Middle Jurassic (Late Bajocian) to Recent. The Mesozoic sediments (Middle Jurassic to Lower Cretaceous) were laid down on a granitic basement. Trap flows resting disconformably on the lower cretaceous Bhuj Member mark the upper limit of the Mesozoic stratigraphy.

The Mesozoic rocks of Kutch are known the world over for their biological entities. Lithostratigraphically these rocks have been originally classified into Patcham, Chari, Katrol and Umia Formations in ascending order. The lithostratigraphic scheme has been reinforced in the last few decades. The younger part of the Umia Formation is represented by coarse-grained, gritty, cross-bedded, apparently unfossiliferous and thick sandstone as Bhuj Member in the lithostratigraphic scheme currently in usage.

It is well developed all over in the Kutch mainland and is mainly constituted of sandstone with interspersed thinner silt and clay interbeds. Body macroinvertebrate fossils are localized in the lower part of the Umia Formation. No report of marine body fossils is available from the upper/later/younger part, i.e. Bhuj Member. Calcareous nanofossils, recorded from the sandstone unit of the lower part of Bhuj Member provide precise date to this marine unit.

The body fossils were possibly not preserved in the sandy facies of the Bhuj sandstone unit, but presence of tiny calcareous nanofossils can be explained having possibly escaped dissolution due to entrapment in the calcareous specks associated with the shale partings. Thirty-two nanofossil species are recorded from profusely bioturbated gymnospermous and pteridophytic leaf-bearing bed attaining black shale nature, which is about 10 m in height exposed along a roadside section on the Bhuj-Nakatran road about 2.5 km west of Bhuj town opposite Jakh temple (Figure 2).

The nonavailability of body fossils and presence of abundant plant fossils in the Bhuj Member has been the main reason to consider it as a fluviatile or continental or fluvio-deltaic deposit by several workers. However, facies association and trace fossil studies interpret a coastal marine environment of deposition for it. These nanofossil forms are recovered from the plant bed which is overlain by bioturbated bed and brown shaly bed (Table 1). The present record of datable nanofossils of early Middle Albian age belonging to CC8 Prediscoeca phera columnata zone with NC8 Tranolithus orionatus total range zone, delimits the age of the lower part of (sandstone unit) the Bhuj Member as early Middle Albian and attests to its shallow-marine, near-shore and warm-water environment of deposition. Thus, future studies of calcareous nanofossils, if present, at various levels in different stratigraphic units of the Kutch Mesozoics in the Kutch Basin may serve as an alternative biological stopwatch subordinate to ammonites, and its integration with the ammonoid-based scheme may be additionally useful for biozonation of the South Tethyan margin in the Jurassic–Cretaceous time period.

On the basis of the ammonite fauna of Aptian age, from Ukra beds of the Umia Formation a lower Cretaceous age was assigned to the upper part of Umia Formation.

Santonian –? Campanian age for upper limit of the Bhuj Member of Umia Formation was provided on the basis of palynological data. SEM pictures of 19 planktonic forams were provided from calcareous argillaceous lithology and erected Khati beds, and assigned Santonian–Campanian age. The identifications are not convincing as the pictures and preservation are poor. Argentiniceras ammonite was described from the Umia Member of the Umia Formation, which provided Early Berriasian age north of Lakhapar in western Kutch. Ammonoid genus Kiliannela was recorded from bed number 14 of Sahera section, bed number 24 of Mundhan section and bed number 40 of Lakhapur section of Umania Member, and the approximate Berriasian/Valanginian boundary was demarcated. Boundaries of Valanginian/Hauterivian are tentatively placed between bivalve-rich Umania/Busul Member and body fossil-devoid Ghuneri Member in Ghuneri section between bed numbers, 4 and 5. The base of the Ghuneri Member is marked as the base of the Hauterivian. Ukra Member is dated as Early Aptian–Early Middle Albian on
the basis of ammonoids. Late Aptian age is provided for the middle part of Ukra Member by the presence of *Australiceras* and *Tropaeum* and Early to Early Middle Albian age is provided for the topmost part of Ukra Member due to the presence of *Lemuroceras* and *Cleoniceras*. The Upper Member is placed between Early Middle Albian and Albian/Cenomanian boundary is placed at ca. 89 m.y. on the basis of fission track age assigned to glauconites immediately below the Deccan Trap in the Ghumeri/Amarsar section (Figure 3).

Along the Bhuj–Nakhatrana road near Kukad Bit village, there is a prominent roadside escarpment section opposite the Jakh temple. The lower part of the Bhuj Member (sensu Krishna) is exposed here as small, isolated cliff section (Figure 2). The sequence is represented by coarse-grained, gritty sandstone at the top (bed 5) underlain by iron-stone

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**Figure 1.** Geological map of part of Kutch Basin showing distribution of Mesozoic formations and sampling locality.

**Figure 2.** Geological section of sampling site on Bhuj–Nakhatrana road opposite Jakh temple.
Table 1. Lithostratigraphic succession of Umia Formation (after Krishna et al.11 and Krishna9) with the diachronous Bhuj Member.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Ammonite data</th>
<th>Age</th>
<th>Radiochronological dating</th>
</tr>
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<tr>
<td>Umia</td>
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<td></td>
<td>Krishna 1987, 2002</td>
<td>Krishna et al.11</td>
<td>E</td>
<td>Biswas3,10</td>
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<tr>
<td></td>
<td>Bhuj Member</td>
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<td>E</td>
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<tr>
<td></td>
<td>Ukra</td>
<td>marine lithosome gritty facies at the base</td>
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<td>Bhuj Formation</td>
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<td></td>
<td>Ghuneri Member</td>
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<td>Katesar Member</td>
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<td>Gritty facies at the base with largest Pleruromastia</td>
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<tr>
<td></td>
<td></td>
<td>Umia Member</td>
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<td></td>
<td>Lower</td>
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</tbody>
</table>

Figure 3. Ammonite dates for various members of Umia = Bhuj Formation tagged with radiochronological data displaying no age control for upper thick sandstone unit.

Figure 4. Stratigraphic range and level of studied nanofossils with respect to zonal schemes.
Figure 5. Light micrographs are printed in the same orientation with respect to the axes of the nicols as observed under the microscope. All forms are magnified 200X. 1a, b–5, Watznaeuria barnesae (Black, 1959) Perch-Nielsen, 1968; 6a, b–8, W. britannica (Stradner, 1963) Reinhardt, 1964; 9a, b, Cyclagelosphaera margerelli Noël, 1965; 10, 11a, b, 13, W. ovata Bukry, 1969; 14, Cyclagelosphaera margerelli Noël, 1965; 15a, b, Watznaeuria sp. 1; 16a, b, Cyclagelosphaera sp. 1; 17, W. ovata Bukry, 1969; 18, Dizygotolithus lehmanii Noël, 1965; 19a, b, Cylindralithus nudus Bukry, 1969; 20a, b, Watznaeuria sp. 2; 21a, b, W. ovata; 22a, b Cyclagelosphaera sp. 2; 23, 24a, b, 25, D. lehmanii Noël, 1965; 26a, b, Cylindralithus nudus Bukry, 1969; 27, Gen et sp. indet; 28, Cyclagelosphaera argoensis Bown, 1992; 29, Hayesites irregularis (Thierstein, 1972) Applegate et al. in Coving & Wise, 1987; 30, Watznaeuria sp. 3; 31a–c, Hayesites irregularis (Thierstein, 1972) Applegate et al. in Coving & Wise, 1987; 32a, b, Zeughabdatus scantula (Bergen, 1994) Rutledge & Bown, 1996; 33, Braarudosphaera cf. B. africana Stradner, 1961; 34a–d, Tranetolithus orionatus (Reinhardt, 1966) Perch-Nielsen, 1968, and 35a, b, Gartnerago numum Thierstein, 1974.
which at places (bed 4) displays heavy and thick intertwined Thalassinosoides burrows (bed 3) with dominance of iron mineral. It is underlain by somewhat greyish shales (bed 2) followed by leaf-bearing carbonaceous shale (bed 1) at the base having Ptyiophyllum flora in partings. The greyish-black shale (bed 1) with profuse flora has also supplied the datable nanofossils discussed herein.

Two samples were collected from the section (Figure 2). The lower sample from carbonaceous shale yielded calcareous nanofossils. Few grams of material was suspended in distilled water. It was shaken with a finger and the cloudy suspension was allowed to settle. Top part of the suspension was taken with a dropper and evenly spread on a preheated hot plate. Two slides each were prepared, one with comparatively coarser material taken from the lower layer of the suspended material and the other with finer material taken from the top layer. The suspension was allowed to dry. One or two drops of Canada balsam was poured over the slides and cover slips were placed over them with the help of a tweezer. Air bubbles were allowed to escape. After proper cooking the slides were removed from the hot plate and kept on an even sheet of blotting paper. The coverslips were evenly pressed and extra Canada balsam was allowed to leave the interface of slide and coverslip. In 1–2 min, the slide is dry and ready for further studies.

A checklist of taxa includes Braarudosphaera cf. B. africana, Cylindroolithus nodus, Cyclagelosphaera aragoensis, Cyclagelosphaera margerelii, Cyclagelosphaera rotactylpeata, Cyclagelosphaera spp., Diazmatolithus lehmani, Eproolithus sp., Gartnerago nanum, Hayesites irregularis, Laguncula pitcheriensis n. sp., Quadrum intermedium, Prediscosphaera columnata, Retecapsa angustiforata, Rucinolithus hayi, Rucinolithus sp., Tranolithus orthionatus, Thoracosphaera saxea, Thoracosphaera sp., Watznaeuria barnesae, W. britannica, Watznaeuria spp., Zygophylobadus scutata, and holococcoliths gen and sp. indet. Genus Laguncula is reported from India through a new species L. pitcheriensis.

Genus Laguncula Balck, 1971

This monospecific genus was described as problematic from the Gulf of Maldenhill and later included in global nanofossils. Small and hollow globular nanofossils consisting of interpenetrant rhombohedra are surmounted by a tube of variable morphology. The type species L. dorothae is reported from Hauterivian of NW African margin.

Laguncula pitcheriensis n. sp.

Figure 8, 15a-b, 16a-b, 17–20, 21a-b

Holotype: 15a-b
Paratypes: 16a-b, 17–20, 21a-b

Name: After pitcher-like appearance.

Age: Early Middle Albian; CC8 P. columnata zone = NC8 T. orionatus total range zone.

Type horizon: Umia Formation, lower part of Bhuj Member.

Type locality: Kutch Basin (Near Bhuj town, opposite Jakh temple on Bhuj–Nakhatrana road section).

Diagnosis: Small, hollow, globular nanofossil with a narrow protuberance.

Description: Single-layered nanofossil surmounted by a distinct protuberance without neck or flaring at the tip. Under-crossed nicols, the nanofossil remains birefringent.

Comparison: L. pitcheriensis n. sp. is comparable in shape with type species L. dorothae, but specimens of L. dorothae illustrated are nearly double in size and may not be conspecific on closer comparison. L. pitcheriensis differs from L. dorothae in possessing long, slender protuberance without any flaring at the tip.

The slide bearing BSIP Museum number 13071 is deposited at the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

The Umia Formation is divisible into basalmost Umia, Gunheri, Ukra and Bhuj Member in ascending order in the western part of the Kutch Basin. However, in the eastern part it is differentiable only as Umia Member (early part) and Bhuj Member (later part). The age for various members is determined by basic chronometers, i.e., ammonites. The studied section represents the lower part of the sandstone unit of Bhuj Member in the Eastern Mainland. It is a chance discovery since the carbonaceous shale unit of the Bhuj Member appears lacking any marine body fossil in outward appearance. No ammonites were recorded in this section of the Kutch Basin and thus precise age could not be assigned to it. The sandstone unit is broadly a thick, coarse grained lido-unit with meagre silt and clay.

The nanofossil assemblage recovered from the lower part of the Bhuj Member representing carbonaceous shale-bearing plant bed is dated Early Middle Albian of Lower Cretaceous age. The assemblage belongs to CC8 P. columnata zone and corresponds with NC8 T. orionatus total range zone (Figure 4) straddling B/C subzone, which falls well within the Tethyan ammonite denticatus zone tenable both in Tethyan as well as in boreal provinces. Presence of P. columnata, Diazmatolithus lehmani and absence of Eiffelithus turrisietfelli attest this age.

The occurrence of these datable calcareous nanofossils of low diversity with moderate preservation from the base of carbonaceous shale plant bed of lower Bhuj Member is significant. The nanofossil assemblage belongs to CC8 P. columnata zone corresponding with NC8 T. orionatus total range zone of Early Middle Albian age (Figure 4).

There is need to look into the entire Bhuj Member below the Deccan Trap for the existence of nanofossils or other marine elements besides ichnofossils. It is also important to find whether marine Late Cretaceous is exposed in Kutch or not. Future nanofossil studies in the Bhuj Member may help to obtain the precise upper age limit of inland seas in the Jurassic–Cretaceous period in the exposed part of Kutch. The dispersed organic matter studies of nanofossils bearing carbonaceous shale sample show high degree of biodegradation (amorphous organic mat-
Figure 6. Light micrographs are printed in the same orientation with respect to the axes of the nicols as observed under the microscope. All forms are magnified 200X. 1, 2a, b, 3a, b, Reticula argustiforata Black, 1971; 4a, b, Prediscosphaera columnata (Stover, 1966) Perch-Nielsen, 1984; 5a–c, Cyclageilosphaera rotaclypeata Bukry, 1969; 6a–c, 7a, b, Rucinolithus hayi Stover, 1966; 8, Epolithus sp.; 9a–c, Quadratium intermedium Varol, 1992; 10, Holococcolith; 11a, b, Quadratum intermedium Varol, 1992; 12, 13, Rucinolithus sp.; 14, Watzaeuria sp. 4; 15a, b, Lagunula ♂ featherensis n. sp., holotype: 16a, b, 17–20, Lagunula ♂ featherensis n. sp., paraotypes; 21a, b, Coccosphere; 22, Thoracosphaera saxea Stradner, 1961 and 23, Thoracosphaera sp.
with few charred grains and suggesting sedimentation between high energy cross-laminated sandstone units, while shallow marine conditions prevailed in the basin.

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Estimation of source parameters for 14 March 2005 earthquake of Koyana–Warna region

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The source parameters for the 14 March 2005 earthquake in the Koyana–Warna region have been estimated using data from three broadband seismological observatories installed by us at regional distances in the Indian Peninsular shield. Spectral analysis of SH-waveform on transverse component of the three-component seismograms is performed. The estimated seismic moment (\(M_0\)), source radius (\(r\)), stress drop (\(\Delta \sigma\)) and moment magnitude (\(M_w\)) for this earthquake are \(3.9 \times 10^{16}\) Nm, 975 m, 19 MPA and 5.1 respectively. The near-surface attenuation factor (\(k\)) is found to be of the order of 0.01 for the stable shield region, suggesting a thin low-velocity sediment beneath the region. The estimated stress drop of the earthquake is higher compared to the other intraplate earthquakes in India. The focal mechanism solution estimated for this event using amplitudes and polarities of direct P- and S-waves suggests the fault plane with strike N312° dip 36° and rake 248°.

Keywords: Earthquake, Koyana–Warna region, source parameters, stress drop.

The Indian Peninsular shield, hitherto considered a stable intraplate environment, appears to be moderately active in the recent times with earthquakes of \(M_0\) 5.0 occurring.

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