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Early Holocene pollen record of vegetation and climate history in response to the monsoonal activity in East Garo Hills, Meghalaya, India

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ABSTRACT

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This study presents a palynological analysis in 2.0 m deep sedimentary soil profile procured from Rongre Swamp of East Garo Hills to document changes in vegetation and climate in response to the monsoonal activity since 10,640 cal. BP. Four palaeovegetation and climate zones were recorded based on the frequencies of major pollen taxa in the region. The first phase was around 10,640–7,540 cal. BP broadly shows the existence of tropical forest in the region under the onset of warm and humid climatic condition. Subsequently, between 7,540–5,490 cal. BP, the forest got enriched with increased values of tropical mixed deciduous and evergreen elements. The vegetation scenario as marked by both deciduous and evergreen elements in increased values support the warm and humid climate in response to the relatively high monsoonal activity. Accordingly, in the third phase between 5,490–1,120 cal. BP, the values of major arboreal pollen taxa, *Shorea*, *Mesua*, *Elaeocarpus* and *Duabanga* have declined as compared to the preceding phase in relation to the relatively less warm and humid climate than the preceding phase in the region. In the last phase around 1,120 cal. BP to present, the forest got deteriorated as evidenced by the decreased values of arboreal pollen taxa. This phase clearly depicts the high anthropogenic activity as evidenced by the abundance of cultural pollen like cereal and *Brassica*.

Key–words—Pollen data, Palaeovegetation, Palynoassemblage, Monsoonal activity, East Garo Hills, Meghalaya.

पूर्वी गारो पहाड़ियां, मेघालय, भारत में मानसूनी सक्रियता की अनुक्रिया में वनस्पति का प्रारंभिक होलोसीन पराग अभिलेख एवं जलवायु इतिहास

एस.के. बसुमतारी, स्वाति त्रिपाठी एवं एस.के. बेरा

सारांश

यह अध्ययन 10,640 वर्ष पूर्व से मानसूनी सक्रियता की अनुक्रिया में वनस्पति एवं जलवायु में परिवर्तनों को प्रलेखित करने में पूर्वी गारो पहाड़ियों के रोंग्रे दलदल से प्राप्त 2.0 मीटर गहरी अवसादी मृदा परिच्छेदिका में परागाणविक विश्लेषण प्रस्तुत करता है। अंचल में मुख्य पराग टैक्सा की आवृत्तियों पर आधारित चार पुरावनस्पति व जलवायु क्षेत्र अभिलिखित किए गए थे। प्रथम प्रवस्था 10,640–7,540 वर्ष पूर्व के लगभग थी। अंचल में कोष्ण एवं आर्द्र जलवायवी स्थिति के प्रारंभ में मोटे तौर पर उष्णकटिबंधीय वन की विद्यमानता दर्शाती है। तत्पश्चात 7,540–5,490 वर्ष पूर्व के मध्य यह वन उष्णकटिबंधीय मिश्रित पतझड़ी व सदाहरित अवयवों के वर्धित मानों से समृद्ध हो गया। वर्धित मानों में पतझड़ी व सदाहरित दोनों अवयवों से यथा चिह्नित वनस्पति परिदृश्य सापेक्षतया उच्च मानसूनी सक्रियता की अनुक्रिया में कोष्ण एवं आर्द्र जलवायु को संबल प्रदान करता है। तदनुसार, 5,490–1,120 वर्ष पूर्व के मध्य तृतीय प्रावस्था में, अंचल में पूर्ववर्ती प्रावस्था की अपेक्षा सापेक्षतया अल्प कोष्ण एवं आर्द्र जलवायु के संबंध में पूर्ववर्ती प्रावस्था की तुलना में मुख्य वृक्षीय पराग टैक्सा *शोरिया मेसुआ, इलेओकार्पस* व *दुआबंगा* के मान क्षीण हुए हैं। 1,120 वर्ष पूर्व के लगभग से वर्तमान तक अंतिम प्रावस्था में वन का क्षय हो गया। जैसा कि वृक्षीय पराग टैक्सा के मानों में न्यूनता से यथा स्पष्ट है। अनाज एवं ब्रेसिका जैसे संवर्धनी पराग की प्रचुरता से यथा सुस्पष्ट यह प्रावस्था उच्च मानवजनिक सक्रियता स्पष्टतः निरूपित करता है।

सूचक शब्द—पराग आंकड़ा, पुरावनस्पति, परागाणुसमुच्चय, मानसूनी सक्रियता, पूर्व गारो पहाड़ियां, मेघालय।

INTRODUCTION

THE flora of northeast India especially Meghalaya is the richest in India and probably in whole Asia. However, in term of floral affinities Meghalaya is closely connected with southeast Asia and southern China (Hooker, 1905; Mehrotra *et al*., 2005). This region of the world is considered by plant scientists and geographers as one of the nuclear areas of early plant domestication (Vivilov, 1949; Sauer, 1952; Harris, 1972). However, Meghalaya may be considered as a botanical paradise and support one of the most diverse and luxuriant tropical vegetation conditions in the world (Kumar *et al*., 2002). Pollen is the best tool to reconstruct the palaeovegetation and climate of the region. Modern palynological works on surface samples have already been carried out from the different parts of Meghalaya, northeast India (Khasi and Jaitia Hills (Gupta & Sharma, 1985; Basumatary *et al*., 2013, 2014, 2017) and East Garo Hills (Basumatary & Bera, 2007). However, no attempt has been made to decipher palaeovegetation and climatic history from this region except few publications from West Garo Hills (Basumatary & Bera, 2010) and South–West Garo Hills (Basumatary *et al*., 2018). Thus, this paper for the very first time represents a reconstruction of palaeovegetation and past climate changes in East Garo Hills of Meghalaya for the entire Holocene Epoch based on pollen records. Past climatic variations based on pollen records were deciphered from the adjacent region of Assam, Indo–Burma region which clearly portray the shift from warm and less humid to warm and increased humid climate between 8390–3450 cal. BP, corresponding to the Holocene thermal maximum (8000–7000 yr. BP). This alteration in humidity could be attributed to an intensified southwest monsoon (Tripathi *et al*., 2020). Thus, our study in East Garo Hills also shed lights and corroborates with such global climatic events, where the forest got enriched with abundance of moist deciduous and evergreen arboreal taxa at the average value of 37.9% between 7,540 to 3,590 cal. BP.

STUDY AREA AND CLIMATE

The Garo Hills in western Meghalaya comprise gentle undulating forested slopes at the edge of the country, adjacent to the Bangladesh plain (Fig. 1). The studied site, Rongre Swamp is lying between N 25º34'11.9" and E 90º34'02.5" under the Rongrenggiri Reserve Forest of East Garo Hills covering an area of about 117.00 hectares. The climate of the area is directly influenced by south–west monsoon and north–eastern winter winds. The mean temperature goes down to 3.5ºC and rise up to 33.5ºC at Garo Hills during mid winter and summer respectively. The mean annual rainfall varies considerably and the whole Garo Hills receive 160.0 to 400.0 cm. Mawsynram (a village about 14 km from Cherrapunji) has the highest rainfall receiving place on the earth. Cherrapunji receives an average of 1114.4 cm rainfall annually, whereas Shillong (state capital) which lies just 53 km north of it, receive only 233.5 cm rainfall.

VEGETATION

The vegetation of the area is dominated by sal (*Shorea robusta*) forest in association with the deciduous and evergreen elements namely, *Schima wallichii*, *Terminalia bellirica*, *Mesua ferrea*, *Duabanga grandiflora*, *Dillenia pentagyna*, *Careya arborea*, *Elaeocarpus aristatus*, *Semecarpus anacardium*, *Syzygium cumunii* and *Emblica officinalis*. The dominant species of the bamboo stands such as *Melacanna bambusoides*, *Dendrocalamus hamiltonii*, *D. sikkimensis*, *D. gigantea*, *Bambusa bambos*, *Chimonobambusa khasiana* and

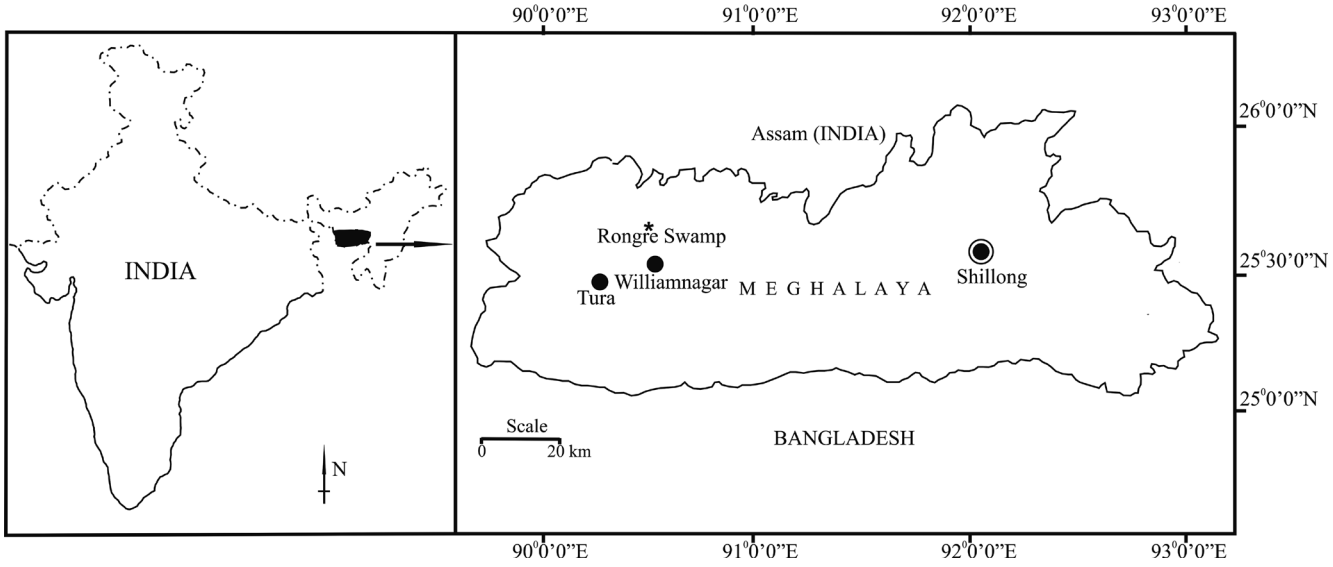


Fig. 1—Location map showing the study area.

Melocanna bambusoides are scatter growing in and around the forest area. The terrestrial herbs are meagrely represented in the forest floor with scattered fern allies such as *Lycopodium clavatum*, *Angiopteris evecta*, *Dryopteris filixmas*, *Blechnum orientale*, *Cyathea gigantea* and *Lygodium japonicum*.

The vegetation of the swamp is composed of Cyperaceae, Poaceae, Onagraceae, Polygonaceae, Ranunculaceae, *Costus speciosus*, *Colocasia esculanta*, etc. as the major plant taxa at the marginal area. Aquatic vegetation in the swamp consists of both angiosperms and few pteridophytes namely *Nymphoides indica*, *Potamogeton pectinatus*, *Nymphaea nouchali*, *Lemna minor*, *Myriophyllum indicum*, *Marsilea minuta*, *Salvinia oblongifolia* and *Azolla pinnata*.

MATERIAL AND METHOD

A 2.0 m deep sedimentary soil profile was procured from southern flank of Rongre Swamp containing 20 samples at the 10 cm interval procured by Hiller's peat auger. In addition four samples for radiocarbon dating were also collected from

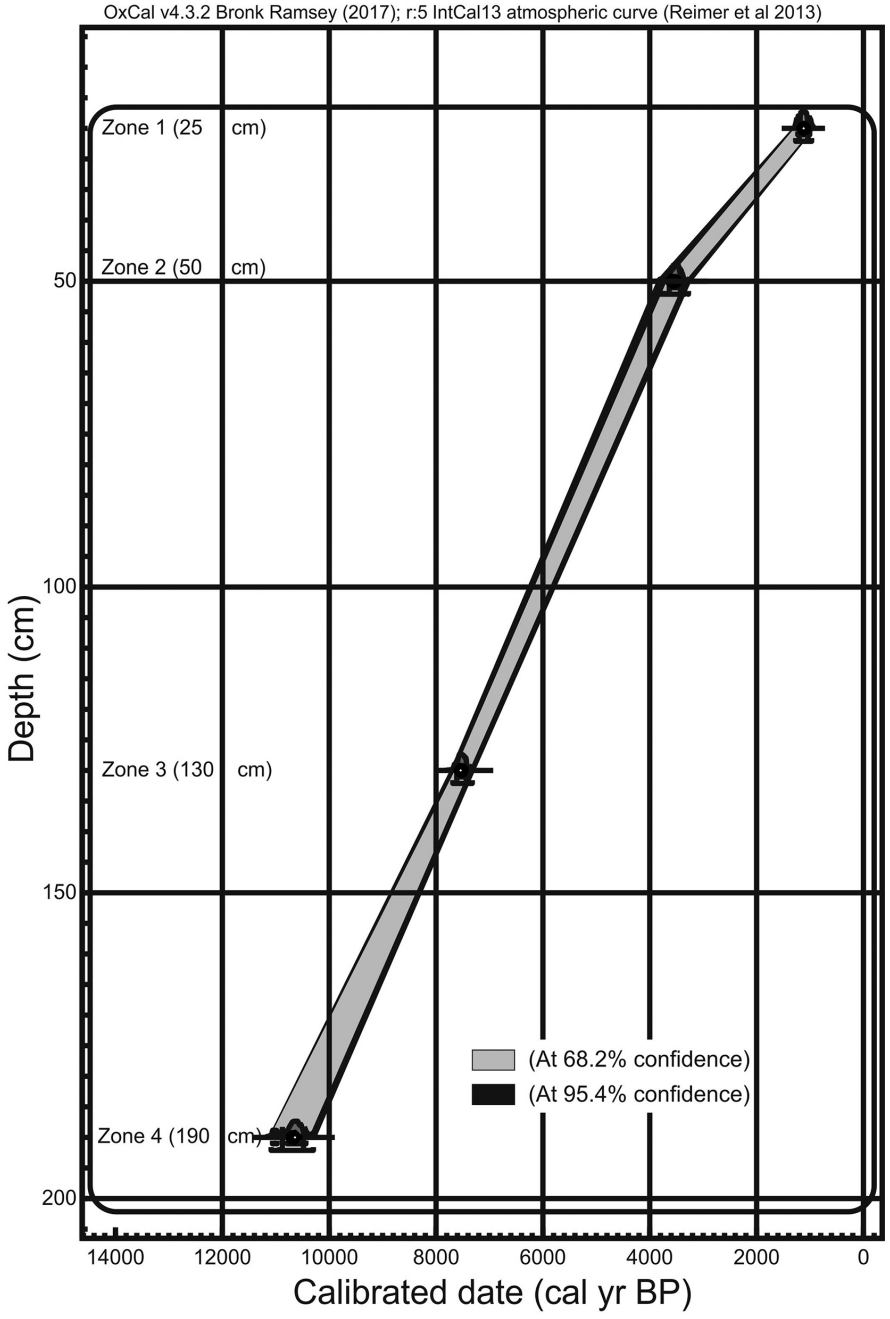


Fig. 2—Bayesian age–depth model of the sedimentary soil profile from Rongre Swamp of East Garo Hills.

suitable horizons of the sediment profile viz., 190, 130, 50 and 25 cm on the basis of lithological variations. The sediment soil samples were pollen analysed employing standard acetolysis method (Erdtman, 1953) as the soil samples were treated with 10% aqueous KOH solution to deflocculate the pollen/spore from the sediments followed by 40% HF treatment to dissolve silica content and acetolysis (9: 1 anhydrous acetic anhydrite to concentrated sulphuric acid, (H_2SO_4) for the removal of cellulose. After that, the samples were treated twice with glacial acetic acid (GAA) and washed 3 or 4 times with distilled water. Finally the material was kept in 50% glycerin solution and a few drops of phenol were also added to protect the processed material from microbial decomposition. The investigated profile is delineated into four distinct lithozones (Table 1) based on the soil colour. The four distinct pollen zones (RS I to RS–IV) have been recognized based on the presence and abundance of the arboreal and non–arboreal pollen taxa in the sedimentary section. The prefixed 'RS' is given after the name of locality (Rongre Swamp) from where the soil profile has been collected and the zones are numbered I–IV from the bottom to top of the section. Excluding the ferns and fungal remains, a total numbers of 200 to 450 pollen grains per sample were counted to construct the pollen diagram. The frequency of the recovered pollen has been calculated in term of total pollen count. The pollen grains are categorized as arboreal (tree and shrub), non–arboreal taxa (terrestrial, marshy and aquatics) and extra–regional (conifers and other broadleaf) taxa. Pollen grains were identified to the most precise taxonomic level possible using pollen key (Erdtman, 1952; Faegri & Iversen, 1989; Moore *et al*., 1991; Bera *et al*., 2007) and with the help of prepared reference slides from the sporothek in Birbal Sahni Institute of Palaeosciences (BSIP), India. The pollen observation and microphotographs were done using Olympus BX–61 microscope with Olympus DP–25 software supported digital camera under 40X magnification (Pl. 1). The pollen diagram was made by using TILIA programme with further modification in Coral Draw–12 software. A Poisson process deposition model (Bayesian age–depth modelling; Bronk Ramsey, 2008) was used to establish the age–depth relationship. The model showed all agreement indexes and convergence indexes higher than the critical values, thus all the four C^{14} dates were retained in the model. The final age–depth model is presented with the 95% and 68% probability range (darker and lighter shades), respectively, for the age of every depth in Fig. 2.

DESCRIPTION OF POLLEN DIAGRAM

For the better understanding of the succession of vegetation and climate since early Holocene, four pollen zones have been recognized in this pollen diagram based on the variations of frequencies of major pollen taxa. Each pollen zone is prefixed by RS after the name of the locality from where the soil profile has been analyzed. These pollen zones are described below separately (Fig. 3).

Pollen Zone RS–I (200–140 cm): Grasses–Asteroideae–Convolvulaceae–*Nymphaea–Semecarpus–Syzygium–Ilex* Assemblage: This pollen zone is covering a time span of 10,640–7,540 cal. BP and characterized by the over dominance of non–arboreal taxa at the average value of 72.1% over arboreal taxa (19.6%) as well as extra–regional taxa (8.3%). Among non–arboreal taxa, grasses (< 60 µm) are predominated with the maximum value of 12.5% followed by Asteroideae (6.2%), Cyperaceae (5.5%), Bambusoideae (5.2%), Cichorioideae (4.2%), *Artemisia* (3.3%), *Xanthium* (2.9%), Lamiaceae (2.8%), Convolvulaceae and Verbenaceae (2.6% each), *Chrozophora* (2.4%), Acanthaceae (2.2%), *Polygonum plebeium* (1.6%), Chenopodiaceae/Amaranthaceae (1.5%), Caryophyllaceae and Brassicaceae (1.2% each). However, Solanaceae, *Impatiens*, *Jussiaea* and *Polygonum serrulatum* are encountered as only marshy taxa at the low to sporadic values. However, among aquatic taxa *Nymphaea* is represented in 1.2% along with sporadic values of *Nymphoides*, *Potamogeton* and *Typha*.

Among the major tree taxa *Shorea robusta* (3.3%), *Syzygium cumunii* and *Ilex* (1.0% each) are encountered at moderate to low values. However, *Garcinia* and *Schima wallichii* (0.9% each), *Terminalia bellirica* (0.8%), *Semecarpus anacardium*, *Sapindus*, *Careya arborea* and *Emblica officinalis* (0.7% each), *Dillenia pentagyna* and *Duabanga* (0.6% each), *Salmalia malabarica* (0.5%) and *Elaeocarpus* (0.4%) are also represented sporadically. Among the shrubby elements, *Melastoma malabathricum* registered the value of 2.4% followed by the sporadic values of *Strobilanthes* and Oleaceae (0.7% each), *Holarrhena* (0.6%), *Symplocos* (0.5%) and *Dombeya* (0.4%). The extra–regional elements are encountered rank wise as *Pinus* (3.0%), *Betula* (2.3%), *Alnus* (2.0%) and *Quercus* (1.3%) respectively.

Pollen Zone RS–II (140–60 cm): Grasses–Cyperaceae–Cichorioideae–Acanthaceae–*Potamogeton–Shorea robusta–Careya*–Magnoliaceae–*Symplocos* Assemblage: This pollen zone is covering a time period of 7,540–3,590 cal. BP and characterized by the dominance of non–arboreals at the tune of 51.5% over arboreals (37.8%) followed by extra–regional elements under the values of 10.7% respectively. Among the major non–arboreal taxa, grasses (> 60 µm) are predominated (7.6%) along with Bambusoideae (4.1%),

Table 1—Detailed description of the lithozones.

Column Depth (in cm)	Lithology
0–30	Greyish clay with rootlets
31–60	Blackish clay with little silt
61–140	Compact organic mud
141–200	Organic mud with little silt

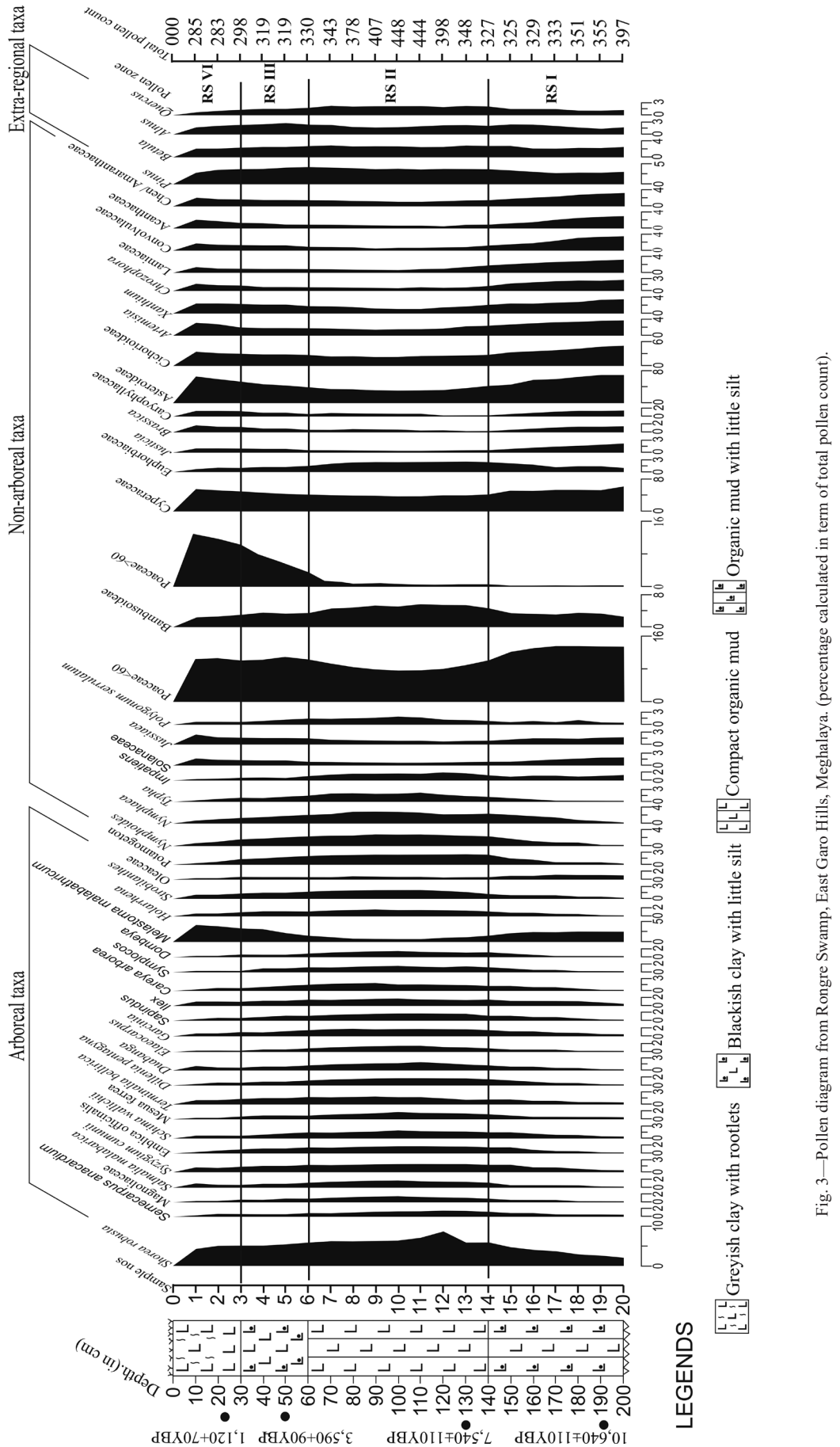


Fig. 3—Pollen diagram from Rongre Swamp, East Garo Hills, Meghalaya. (percentage calculated in term of total pollen count).

Cyperaceae (4.0%), Asteroideae (3.5%), Cichorioideae (2.4%), *Artemisia* (1.8%), *Xanthium* (1.5%) and Verbenaceae (1.3%) respectively. However, Lamiaceae, *Chrozophora* and Chenopodiaceae/Amaranthaceae (0.9% each), Acanthaceae and Convolvulaceae (0.8% each), Caryophyllaceae (0.6%), *Polygonum plebeium* and Brassicaceae (0.5% each) are represented sporadically. Solanaceae, *Jussiaea*, *Polygonum serrulatum* and *Impatiens* are represented as major marshy taxa at the tune of 1.5% to 2.4%. *Nymphoides* (2.7%), *Nymphaea* (2.6%), *Potamogeton* (2.5%) and *Typha* (1.9%) are represented as a group of typical aquatic elements.

The major tree taxa are represented rankwise by *Shorea robusta* (6.5%), *Syzygium cumunii* (1.9%), *Emblica officinalis*, *Schima wallichii*, *Mesua ferrea*, *Terminalia bellirica*, *Dillenia pentagyna*, *Garcinia*, *Sapindus* and *Careya arborea* (1.7% each), *Duabanga* and *Ilex* (1.6% each), *Salmalia malabarica* (1.5%), *Semecarpus anacardium*, Magnoliaceae and *Elaeocarpus* (1.3% each) respectively at moderate to low values. The major shrubby elements are registered as *Strobilanthes* (2.0%), *Holarrhena* (1.5%), *Symplocos* and *Dombeya* (1.3% each) and *Melastoma malabathricum* (1.0%) respectively. Sporadic occurrence of Oleaceae (0.6%) is significant. The extra–regional elements like *Pinus* (3.8%), *Betula* (2.7%), *Quercus* (2.2%) and *Alnus* (2.1%) are encountered with moderate values in regular basis.

Pollen Zone RS–III (60–30 cm): Grasses–Asteroideae–*Xanthium–Typha–Shorea robusta–Syzygium–Strobilanthes* Assemblage: This pollen zone is covering a time period of 3,590–1,120 cal. BP, and characterized by the predominance of non–arboreal taxa within the average frequency of 59.1% over arboreal taxa (30.0%). The extra–regional elements are also registered continuously at good value (10.8%). Among major non–arboreal taxa, grasses (<60 μm and >60 μm) are dominated within the value of 10.9% and 11.7% respectively. Other associated herbaceous taxa are encountered as Cyperaceae (4.4%), Asteroideae (4.3%), Bambusoideae (2.9%), Cichorioideae (2.8%), *Xanthium* (2.1%), *Artemisia* (1.9%), Chenopodiaceae/Amaranthaceae and Verbenaceae (1.5% each), Convolvulaceae (1.1%) and Acanthaceae (1.0%) respectively at moderate to low value. However, *Chrozophora* and Lamiaceae (0.9% each), *Polygonum plebeium*, Brassicaceae and Caryophyllaceae (0.8% each) are encountered in sporadic values. *Jussiaea* (1.3%), *Polygonum serrulatum* (1.2%), Solanaceae (1.1%) and *Impatiens* (0.6%) are registered as marshy elements. The aquatic taxa are represented rank wise as *Nymphoides* (2.2%), *Nymphaea* (1.9%), *Potamogeton* (1.9%) and *Typha* (1.2%) respectively.

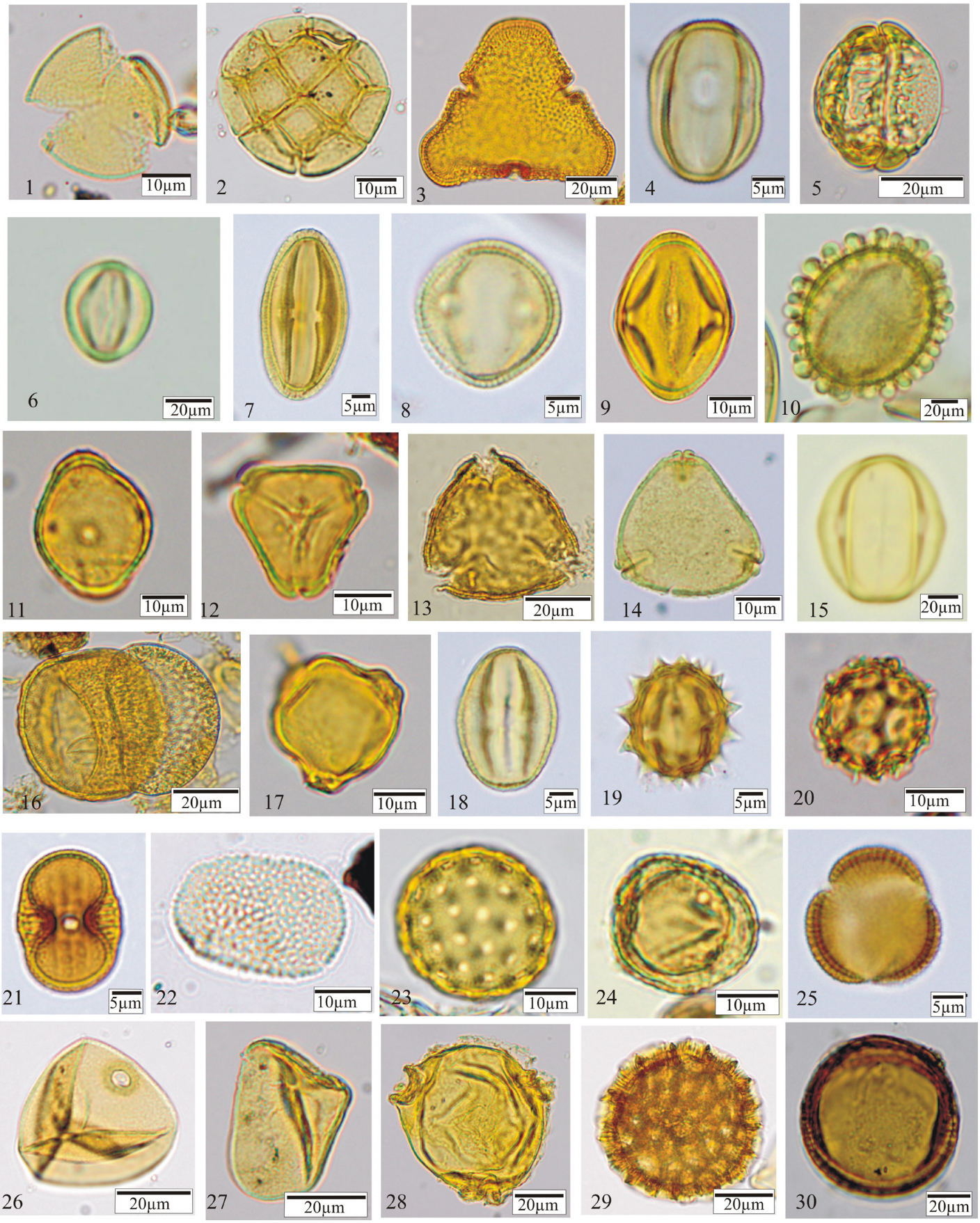
Among tree taxa *Shorea robusta* (5.4%) is dominated. Besides, the other sal associates namely *Terminalia bellirica* and *Syzygium cumunii* (1.7% each), *Ilex* and *Emblica officinalis* (1.3% each), *Garcinia*, *Schima wallichii* and *Careya arborea* (1.2% each), *Sapindus* (1.1%), *Salmalia malabarica*, *Dillenia pentagyna* and *Duabanga* (1.0% each) are represented in moderate to low frequencies. However, *Mesua ferrea* (0.9%), Magnoliaceae (0.8%), *Semecarpus anacardium* and *Elaeocarpus* (0.7% each) are encountered sporadically. Among shrubby elements, *Melastoma malabathricum* (2.3%), *Strobilanthes* (1.7%), *Holarrhena* (1.2%) and *Symplocos* (1.0%) are registered as the major elements. Besides, *Dombeya* (0.7%) and Oleaceae (0.6%) have showed their sporadic representation in the assemblage. The extra–regional elements are represented by *Pinus* (4.0%), *Betula* (2.6%), *Alnus* (2.6%) and *Quercus* (1.7%) respectively at the moderate values as obvious.

Pollen Zone RS–IV (30–0 cm): Grasses–Cyperaceae–*Artemisia–Typha–Shorea robusta–Terminalia–Melastoma* Assemblage: This upper pollen zone with a time period of 1,120 cal. BP to present is characterized by the predominance of non–arboreal taxa at the tune of 69.2% over arboreal taxa (22.1%). The extra–regional elements are also registered continuously at the value of 8.6%. Among major non–arboreal taxa, grasses (< 60 μm and > 60 μm) are dominated within the value of 13.5% to 14.6% respectively. Other associated herbaceous taxa are reflected as Asteroideae (6.0%), Cyperaceae (5.3%), Cichorioideae (3.2%), *Artemisia* (2.7%), Bambusoideae (2.5%), *Xanthium* (2.4%), Chenopodiaceae/

PLATE 1

Pollen assemblage recovered from the Rongre Swamp, East Garo Hills, Meghalaya. →

1. *Shorea robusta*
2. *Albizia lebbeck*
3. *Salmalia malabarica*
4. *Terminalia bellerica*
5. *Barringtonia* sp.
6. *Elaeocarpus* sp.
7. *Semecarpus anacardium*
8. *Emblica officinalis*
9. *Lagerstroemia* sp.
10. *Ilex* sp.
11. *Duabanga*
12. *Syzygium* sp.
13. *Schima wallichii*
14. *Symplocos* sp.
15. *Melastoma malabathricum*
16. *Pinus* sp.
17. *Betula* sp.
18. *Quercus* sp.
19. Tubuliflorae
20. Liguliflorae
21. *Justicia simplex*
22. *Impatiens* sp.
23. Chenopodiaceae
24. *Xanthium* sp.
25. Brassicaceae
26. Poaceae
27. Cyperaceae
28. Onagraceae
29. *Polygonum* sp.
30. *Nymphaea* sp.


1 10µm
2 10µm
3 20µm
4 5µm
5 20µm
6 20µm
7 5µm
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28 20µm
29 20µm
30 20µm

PLATE 1

Table 2—Some important pollen marker taxa identified and characterized from the pollen assemblages recovered from the sedimentary soil samples from the Rongre Swamp of East Garo hills, Meghalaya.

S. No.	Marker pollen taxa	Ecological significance
1.	*Shorea robusta* (Dipterocarpacaeae)	Deciduous/high rainfall
2.	*Salmalia* (Malvaceae)	Deciduous
3.	*Terminalia* (Combretaceae)	Deciduous
4.	*Syzygium* (Myrtaceae)	Deciduous/high rainfall
5.	*Dillenia* (Dilleniaceae)	Deciduous
6.	*Semecarpus anacardium* (Anacardiaceae)	Deciduous
7.	*Emblica officinalis* (Euphorbiaceae)	Deciduous
8.	*Albizia* (Fabaceae)	Deciduous
9.	*Schima wallichii* (Theaceae)	Evergreen/high rainfall
10.	*Mesua ferrea* (Calophyllaceae)	Evergreen/high rainfall
11.	Magnoliaceae	Evergreen/high rainfall
12.	*Elaeocarpus* (Elaeocarpaceae)	Evergreen/high rainfall
13.	*Lagerstroemia* (Lythraceae)	Deciduous/Riparian
14.	*Garcinia* (Clusiaceae)	Evergreen/high rainfall
15.	*Duabanga* (Lythraceae)	Riparian/high rainfall
16.	*Ilex* (Aquifoliaceae)	Evergreen/high rainfall
17.	*Careya arborea* (Myrtaceae)	Riparian/high rainfall
18.	*Melastoma malabathricum* (Melastomaceae)	Deciduous
19.	Bambusoideae	Bamboo forest/high rainfall
20.	*Impatiens* (Balsaminaceae)	Riparian/high rainfall
21.	Cyperaceae	Marshy/swamp
22.	*Jussiaea* (Onagraceae)	Marshy/Aquatic/swamp
23.	*Polygonum* (Polygonaceae)	Marshy/swamp
24.	*Xanthium* (Asteraceae)	Marshy/swamp
25.	*Nymphoides* (Menyanthaceae)	Aquatic/high rainfall
26.	*Nymphaea* (Nymphaeaceae)	Aquatic/high rainfall
27.	*Potamogeton* (Potamogetonaceae)	Aquatic/high rainfall
28.	*Typha* (Typhaceae)	Aquatic/high rainfall
29.	Cereal **(**Poaceae)	Crop/human activity
30.	*Brassica* (Brassicaceae)	Crop /human activity
31.	Euphorbiaceae	Terrestrial herbs/high rainfall
32.	Convolvulaceae	Perennial/terrestrial herb

Amaranthaceae (2.0%), Verbenaceae (1.8%), Acanthaceae (1.7%), Convolvulaceae, Solanaceae, *Chrozophora* and Brassicaceae (1.5% each), Caryophyllaceae (1.4%), Lamiaceae (1.2%) and *Polygonum plebeium* (1.0%) respectively at moderate to low values. Solanaceae, *Impatiens*, *Jussiaea* and *Polygonum serrulatum* are registered as marshy elements under the value of 0.7% to 1.5%. The major aquatic taxa like *Nymphoides* (1.1%) and *Nymphaea* (1.0%) are recorded in low values. Moreover, *Potamogeton* (0.8%) and *Typha* (0.7%) are represented sporadically.

Among tree taxa, *Shorea robusta* is predominated at the value of 4.7% followed by other associates namely *Terminalia bellirica* (1.2%), *Syzygium cumunii* and *Ilex* (1.0% each), at lower value. Besides, *Salmalia malabarica*

(0.9%), *Emblica officinalis* (0.7%), *Semecarpus anacardium* and *Dillenia pentagyna* (0.6% each), *Mesua ferrea* (0.9%), *Garcinia* (0.8%), *Schima wallichii* (0.7%), *Duabanga* and *Sapindus* (0.6% each), *Careya arborea* and Magnoliaceae (0.5% each) and *Elaeocarpus* (0.3%) as semi–evergreen taxa are also represented sporadically. Among shrubby elements, *Melastoma malabathricum* (3.8%) and *Strobilanthes* (1.2%) are registered as the major elements. However, *Holarrhena* (0.8%), *Dombeya* and Oleaceae (0.5% each) and *Symplocos* (0.3%) have showed their sporadic representation in the assemblage. The extra–regional elements are represented by *Pinus* (3.3%), *Betula* (2.2%), *Alnus* (2.1%) and *Quercus* (1.0%) respectively at the moderate to low values.

DISCUSSIONS

Reconstruction of Palaeovegetation and climate in response to the monsoonal activity

The pollen data of studied swamp made it possible to decipher the four palaeovegetation and climate changes in East Garo Hills and its neighbouring areas covering a time span of 10,640 cal. BP to present.

The first phase was between 10,640–7,540 cal. BP and broadly demonstrate the existence of tropical mixed deciduous forest composing of *Shorea robusta*, *Syzygium cuminii*, *Terminalia*, *Duabanga* and *Semecarpus* in the region. The presence of marshy and aquatics taxa such as Cyperaceae, *Jussiaea*, *Nymphaea*, *Typha* and *Nymphoides* in the pollen assemblage are suggestive of the perennial water logged condition in the region. The recovery of evergreen taxa namely Magnoliaceae, *Mesua ferrea* and *Elaeocarpus* in the pollen assemblage is indicative of the rainfall activity in the region. The extra–regional taxa are represented by *Pinus*, *Betula* and *Alnus* at the average value of 8.7% indicative of the high wind activity in the region. The overall pollen assemblage as reflected by the sedimentary soil profile implies the existence of tropical mixed deciduous forest under the onset of warm and humid climatic condition in and around the East Garo Hills.

During the second phase between 7,540–3,590 cal. BP, the forest got enriched with abundance of moist deciduous and evergreen arboreal taxa at the average value of 37.9%. Among the major tree taxa *Shorea robusta* was dominant and the other associates chiefly *Semecarpus anacardium*, *Terminalia bellirica*, *Salmalia malabarica* and *Dillenia* were also continuously represented in the pollen assemblage. The regular presence of evergreen elements namely *Mesua ferrea*, Magnoliaceae, *Garcinia*, *Duabanga* and *Elaeocarpus* was observed in the pollen assemblage and suggestive of the perennial river and streamlet system in response to high rainfall activity in the region. The presence of evergreen taxa in the pollen assemblage was suggestive of the heavy rainfall in this region (Nair *et al*., 2010) which exactly reflected in the study area. However, the average value of non–arboreals comprising both marshy and terrestrial herbs have been decreased (41.9%) and subsequently aquatic pollen taxa namely *Nymphaea*, *Nymphoides*, *Typha* and *Potamogeton* are increased (9.7%) as compared to the preceding phase suggesting wider and perennial water logged condition in response to the high monsoonal activity in the region. The presence of *Nymphaea* pollen indicate open water system (Innes *et al*., 2010) in and around the study area which was consistently observed in the pollen assemblages. This sequence of vegetation indicates the occurrence of good monsoon resulting the formation of organic rich soil which allows the expansion of the rich floristic under the influence of warm and humid climatic condition. The abundance of *Syzygium* and Euphorbiaceae is significant in the pollen assemblage as these taxa indicate high precipitation and atmospheric humidity during sedimentation (Nair *et al*., 2010). Increased value of Bambusoideae pollen indicates the consolidation of Bamboo thickets in and around this region in response to the high rainfall activity in the region. The extra–regional taxa (10.8%) like *Pinus*, *Betula* and *Alnus* are encountered in slightly higher values than the preceding phase supporting the strong wind activity in and around the vicinity areas. The documented high frequency of arboreal and aquatic pollen taxa is indicative of the dense forest under warm and humid condition in response to the high rainfall activity in the region. Some selected pollen and spores are identified and characterized including their ecological significance (Table 2). It has already been cleared from the earlier pollen analysis of lower Brahmaputra Valley of Assam that the south–west monsoon became active at the termination of the Younger Dryas with further weakening during mid–Holocene (Dixit & Bera, 2013). Our inferences support these monsoonal variations.

In the third phase between 3,590–1120 cal. BP, the major arboreal taxa namely *Shorea robusta* was gradually declined. Other sal associated taxa like *Salmalia malabarica*, *Dillenia pentagyna*, *Terminalia bellirica*, *Dombeya* and *Sapindus* are also encountered in decreased frequencies. The evergreen taxa like, *Mesua ferrea*, Magnoliaceae, *Elaeocarpus* and *Garcinia* are also displayed in relatively decreased values. Dry period are identified by low frequencies of arboreal pollen taxa (van Campo *et al*., 1996; Limaye *et al*., 2007) which could be well evident in our studied samples. The extra–regional taxa such as *Pinus*, *Betula* and *Alnus* have been registered at the value of 8.6% without much significant changes and indicative of the wind activity in the region. Simultaneously, the value of *Impatiens* and Euphorbiaceae are also declined at faster rate indicating decreased monsoonal activity in comparison to the preceding phase. However, the terrestrial non–arboreals (69.2%) mainly Poaceae, Tubuliflorae and *Artemisia* have been registered in extremely high value suggesting deterioration of the primary forestland in the region. The increased value of *Artemisia* in any pollen assemblage indicate dry climate (Ma *et al*., 2004) in the region which could be noted in our region.

Similarly, the decreased value of Bambusoideae pollen in the pollen assemblage is indicative of the reduction in Bamboo stakes in and around the study area. The increased value of *Melastoma malabathricum* suggests deforestation in relation to the anthropogenic activity in the region. The increased value of Cerealia, Brassicaceae and other cultural pollen especially *Xanthium* and Chenopodiaceae/Amaranthaceae depicts an acceleration of pastoral activity. Aquatic taxa (5.0%) have also been observed in decreased value and indicative of the relatively dry climate and decreased perennial water logged condition in and around the study region.

Lastly, during the recent phase since 1,120 cal. BP to present, the major arboreal taxa *Shorea robusta* was continuously declined as the preceding phase. The other associated taxa mainly *Salmalia malabarica*, *Dillenia pentagyna*, *Terminalia bellirica*, *Dombeya* and *Sapindus* are also consistently decreased in frequency resulting in to the sparse occurrence of the tropical mixed deciduous forest. The evergreen and marshy taxa such as *Mesua ferrea*, Magnoliaceae, *Elaeocarpus*, *Nymphoides*, *Lemna* and *Potamogeton* have also been observed in decreased values in comparison to the preceding phase. The decreased value of evergreen taxa along with *Impatiens* pollen in the pollen assemblage was suggestive of the comparatively low rainfall activity than the preceding phase in this region. Thus, our pollen inferences are quite matching with the speleothem oxygen isotope records which claimed that the latter phase of the Medieval Climate Anomaly (MCA; 1060 to 1200 CE) was quite drier in contrast to the earlier intervals. The Indian Summer Monsoon was generally weak during the Little Ice Age (LIA; 1350 to 1850 CE) with short–term pulses of high precipitation when sun–spot activity was high (Dutt *et al.,* 2020). The decreased value of aquatic taxa indicates drying of perennial waterlogged condition in response to the poor rainfall and anthropogenic activity in and around the vicinity areas. The increased value of *Melastoma malabathricum* is signifies clearance of forests. The increased values of Cerealia (>60 μm), Brassicaceae and other cultural pollen taxa especially *Xanthium*, *Artemisia* and Chenopodiaceae/Amaranthaceae in the pollen assemblage is indicative of the regular anthropogenic activity in the region. The drastic soil erosion occurred deforestation and heavy rainfall leads to the drastic soil erosion in and around Garo Hills. The continuous soil erosion is further stopping the tree regeneration and the deteriorated forest has converted to the open land with scarce vegetation (Bera *et al.,* 2006). However, this phase is well corroborated with the southwestern part of Garo Hills (Basumatary *et al*., 2018) where, the high level of anthropogenic activity occur in the East Garo Hills. This data is also very helpful to reconstruct the palaeovegetation and climate in the Meghalaya and to correlate with the other part of the northeast India. These pollen results from East Garo Hills also corresponds to the palaeoclimatic data from the adjacent region in Manipur in northeast India which shows the expansion of open–vegetation and a contemporaneous reduction of trees since 600 yr BP owing to a reduction in monsoon precipitation (Tripathi *et al.,* 2018).

CONCLUSIONS

The four palaeovegetation and climatic changes have been displayed in the East Garo Hills of Meghalaya since early Holocene to present. The rainfall variations and anthropogenic activity have been identified as the main factors to control the vegetation and climate changes in East Garo Hills. The deforestation in relation to the human activity has been observed in East Garo Hills during1,120 cal. BP to present. This regional pollen data will be very helpful to study and correlate with the other part of the India especially in the tropical region and to generate a high resolution palaeoclimatic data in this high rainfall terrain and correlate with adjacent regions.

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REFERENCES

Basumatary SK & Bera SK 2007. Modern pollen–spore assemblage from sediment of tropical moist deciduous forest, East Garo Hills, Meghalaya. Journal of Palynology 43: 111–118.

Basumatary SK & Bera SK 2010. Development of vegetation and climate change in West Garo Hills since late Holocene: pollen sequence and anthropogenic impact. Journal of Indian Botanical Society 89: 143–148.

Basumatary SK, Dixit Swati, Bera SK & Mehrotra RC 2013. Modern pollen assemblages of surface samples from Cherrapunjee and its adjoining areas, Meghalaya, northeast India. Quaternary International 298: 68–79.

Basumatary SK, Bera SK, Sangma SN & Marak G 2014. Modern pollen deposition in relation to vegetation and climate of Balpakram Valley, Meghalaya, northeast India: Implications for Indo–Burma palaeoecological contexts. Quaternary International 325: 30–40.

Basumatary SK, Gogoi B & Prasad Vandana 2017. Characteristic modern pollen assemblages in relation to vegetation types in the East Khasi Hills, northeast India. Palynology 41(2): 162–170.

Basumatary SK, Tripathi Swati, Thakur B, Jalil A & Rahman A 2018. Mid–Holocene vegetation and climatic changes in Southwestern Garo Hills, Meghalaya, northeast India based on pollen records. Geophytology 48(2): 103–112.

Bera SK, Basumatary SK, Agarwal A & Ahmed M 2006. Conversion of forestland in Garo Hills, Meghalaya for construction of roads: A threat to the environment and biodiversity. Current Science 91: 281–284.

Bera SK, Basumatary SK & Dixit S 2007. Studies on pollen morphology and phenological characteristics of some economically important arborescent taxa of tropical forest, lower Brahmaputra Valley, Assam, North East India. Journal of Palynology 43: 1–19.

Bronk Ramsey C 2008. Deposition models for chronological records. Quaternary Science Reviews 27: 42–60.

Dixit S & Bera SK 2013. Pollen–inferred vegetation vis–à–vis climate dynamics since Late Quaternary from western Assam, Northeast India: Signal of global climatic events. Quaternary International 286: 56–68.

Dutt S, Gupta AK, Cheng H, Clemens SC, Singh RK & Tewari VC 2020. Indian Summer Monsoon variability in northeastern India during the last two millennia. Quaternary International doi: https: //doi.org/10.1016/j.

quaint.2020.10.021.
Erdtman G 1952. Pollen Morphology and Plant Taxonomy, Waltham, Mass; USA.
Erdtman G 1953. An Introduction to Pollen Analysis, Waltham, Mass; USA.
Faegri K & Iversen J 1989. Textbook of pollen analysis, 4th Edition,Wiley, Chichester.
Gupta HP & Sharma C 1985. Pollen analysis of modern sediments from Khasi and Jaintia Hills, Meghalaya, India. Journal of Palynology 21: 167–173.
Harris DR 1972. The origin of agriculture in the tropics. American scientist 60: 180–193.
Hooker JD 1905. Himalayan Journals, London.
Innes J, Blackford J & Simmons I 2010. Woodland disturbance and possible land–use regimes during the Mesolithic in the English uplands: pollen, charcoal and non–pollen palynomorph evidence from Bluewath beck, North York Moors, UK. Vegetation History and Archaeobotany 19: 439–452.
Kumar A, Gupta AK, Marcot BG, Saxena AM, Singh SP & Marak TTC 2002. Management of forests in India for biological diversity and forest productivity, a new perspective. Volume IV: Garo Hills Conservation Area (GCA). Wildlife institute of India–USDC Forest service collaborative project report, Wildlife Institute of India, Dehra Dun: 206.
Limaye RB, Kumaran KPN, Nair KM & Padmalal D 2007. Non–pollen palynomorphs as potential palaeoenvironmental indicators in the late Quaternary sediments of the West Coast of India. Current Science 92(10): 1370–1382.
Ma Y, Zhang H, Pachur HJ, Wu¨nnemann B, Li J & Feng Z 2004. Modern pollen–based interpretations of mid–Holocene palaeoclimate (8500 to 3000 cal. BP) at the southern margin of the Tengger Desert, northwestern China. The Holocene 14(6): 841–850.
Mehrotra RC, Liu XQ, Li CS, Wang YF & Chauhan MS 2005. Comparison of the Tertiary flora of southwest China and northeast India and its significance in the antiquity of the modern Himalayan flora. Review of Palaeobotany and Palynology 135: 145–163.
Moore PD, Webb JA & Collinson ME 1991.Pollen Analysis, Blackwell, Oxford.
Nair KM, Padmalal D, Kumaran KPN, Sreeja R, Limaye RB & Srinivas R 2010. Late quaternary evolution of Ashtamudi–Sasthamkotta lake systems of Kerela, south west India. Journal of Asian Earth Science 37(4): 361–372.
Sauer CO 1952. Agricultural origin and dispersal, Cambridge, M. I. T., press.
Tripathi S, Singh YR, Nautiyal CM & Thakur B 2018. Vegetation history, monsoonal fluctuations and anthropogenic impact during the last 2,330 years from Loktak Lake (Ramsar site), Manipur, northeast India: a pollen based study. Palynology (Taylor & Francis) 42(2): 406–419.
Tripathi S, Thakur B, Nautiyal CM & Bera SK 2020. Floristic and Climatic reconstruction in Indo–Burma region for the last 13000 cal. yr: A palynological interpretation from endangered wetlands of Assam, northeast India. The Holocene 30(2): 315–331.
Van Campo E, Cour P & Sixuan H 1996. Holocene environmental changes in Bangong Co Basin (Western Tibet) Part 2, The pollen record. Palaeogeography Palaeoclimatalogy Palaeoecology (120): 49–63.
Vivilov NI 1949. The origin, variation, immunity and breeding of cultivated plants, Chronica Botanica 3.