This type of generalized equations developed here are of much use specially for estimating forest resources and thereby estimating regional carbon sequestration. It was found that only $dbh^2 \times$ height was the most stable and also the best predictor of tree biomass in case of all the four districts and the simple allometric equation developed using this predictor can give a robust estimate of the total biomass production of teak grown in this area without any kind of site-specific relationships.

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Evidence of wildfires in the Late Permian (Changsinghian) Zewan Formation of Kashmir, India

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The first record of palaeo-wildfire evidence in the form of charcoal is documented from the Late Permian Zewan Formation of the Kashmir region, northwest Himalaya. This evidence is in the form of fragments of tracheids that show homogenized cell walls, a characteristic feature of charcoal. Considering that palaeo-wildfire studies provide important palaeoecological information, the present study is significant, as it allows reconstructing new information about environmental conditions during the deposition of the sediments of the Late Permian Zewan Formation.

Keywords: Charcoal, Gondwana, Himalayan region, Late Palaeozoic, marine environment.

THE Tethyan realm has been globally accepted as a hub for geoscientific studies, and Kashmir – a part of north west Himalayan region, in particular, has been considerably explored for its wealth of data on various geoscientific aspects including stratigraphy, geochemistry and palaeontology of its Carboniferous, Permian and Triassic sediments[1]. However, palaeo-wildfire studies have so far never been carried out for this area.

Although numerous Late Palaeozoic palaeo-wildfire studies have been carried out in the Northern Hemisphere (e.g. Europe, North America and China), those from Gondwana areas are not that common[2,3]. Despite the first description of charcoal made by Glasspool[4] from the Permian of Australia, macroscopic charcoal evidences have been recorded from Brazil, South Africa, India[3] and Antarctica[5] only recently.

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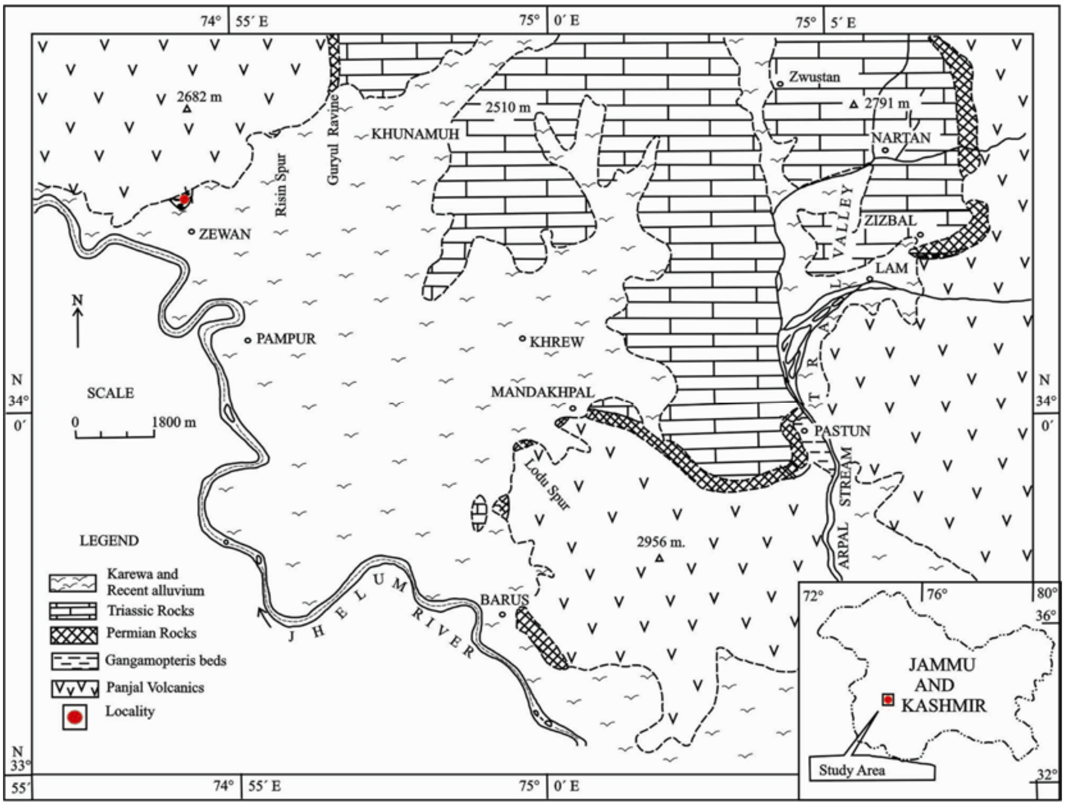

Figure 1. Geological map showing position of the sampling locality at the Zewan spur in Kashmir (after Bhat and Bhat, 1997).

Since the Middle Permian, severe palaeoenvironmental changes took place on Gondwana[6]. In that way, the macroscopic charcoal studies in Late Permian strata are highly significant to understand the regional and global events which culminated in the Permo-Triassic extinction event.

For India, so far, substantiated evidence of palaeo-wildfires (i.e. macroscopic charcoal) is only known for the Late Permian Raniganj Formation, Raniganj Coalfield[7] and for the Barren Measure Formation, South Karanpura Coalfield[8], Damodar Basin. On the other hand, records of abundant inertinites in coals, indicating that wildfires were common, are widely described for the Permian Indian coal seams[9].

With an aim to contribute to the understanding of palaeo-wildfire dynamics during the Late Palaeozoic on Gondwana, we report here the occurrence of meso-charcoal in sediments from the Late Permian (Changhsingian) Zewan Formation of Kashmir, as a direct evidence of palaeo-wildfires.

Kashmir Valley, with a NW–SE trend, lies between the Zanskar and Pir Panjal ranges. The valley measures 135 km in length and 40 km width in its middle, where it has its maximum width. It is surrounded by mountain ranges on all the sides, except at the narrow gorge of river Jhelum at Baramulla[10]. Kashmir is one of the rare regions where no break between Permian and Triassic exists[11] and its stratigraphy was initially established by Lydekker[12]. The Late Palaeozoic sediments of Kashmir are known as Syringothyris Limestone, Fenestella Shale (Early Carboniferous), Agglomeratic Slate (Late Carboniferous), Nishatbagh Formation, Panjal Traps, Mamal Formation (Early Permian) and the marine Late Permian (Changhsingian) Zewan Formation[13,14]. The Permian rocks of Kashmir show marked variation in lithology and have attracted attention of geoscientists owing to their stratigraphic and palaeontological relevance. From the Permian rocks, plant fossils are found only in two horizons – below and above the Panjal Traps. The Nishatbagh beds lying below Panjal Traps consist mostly of tuffaceous slate/shale and the beds above the traps contain novaculite, limestone, tuffaceous, carbonaceous, purple and pinkish shales with arenite, and are known as Mamal Formation[13]. Marine deposits of Zewan Formation, which lie above the plant bearing Mamal Formation, constitute a well-marked horizon in the geology of Kashmir. The name 'Zewan beds' was coined by Godwin-Austen in 1864 after the Village Zewan in the Vihi area[10]. Apart from the type locality in Zewan spur, the beds of Zewan Formation are also exposed in Barus, Risin spur and Guryul Ravine in Srinagar area, and were initially studied by different workers[15–17]. Plant mega remains are not known from any locality of the Zewan Formation, however, recently a few pollen taxa like non-taeniate bisaccate pollen *Alisporites* sp., taeniate bisaccate pollen *Lunatisporites gopadensis*, *Crescentipollenites fuscus*, together with the trilete spore *Verrucosisporites* sp. and taeniate bisaccate pollen *Protohaploxypinus* sp., have been recorded from the members C and D of the Zewan Formation exposed at Guryul Ravine[1].

The study area Zewan spur is situated about 15 km away from Srinagar and 3 km from Guryul Ravine (Permian–Triassic boundary) section (Figure 1). The exposure of fresh outcrops of Zewan Formation covered with crinoids and colonies of bryozoans are due to the result of quarrying in the area. These beds consist of thick bedded, bioturbated, sandy-silty claystones with lenses and thin beds of crinoid ossicles. Horizons of dark to bluish gray shale with thin interbedded limestone full of bryozoan colonies (*Protoretepora ampla*) are encountered. The assemblage of bryozoan colonies is embedded in the shale associated with limestone lenses/calcareous mudstone (Figure 2). At Zewan spur, the section is partially exposed; the upper part is covered by the Karewa Group and recent to sub-recent talus and scree accumulation. The lower 19 m sequence consists of shallow marine sandy bioclastic limestone, shale, sandstone alternating with micaceous sandy shale, characterized by bryozoans, crinoids, calcareous algae and foraminifera. This sequence displays parallel, thickly bedded nature and bioturbations. This sequence is followed up by a 35 m thick, dark, gray, massive and hard, coarsely crystalline limestone alternating with sandy shale, thickly bedded and graded in nature. These deposits resemble delta-platform deposits with open marine influence shown by brachiopods, bivalves and echinoderms.

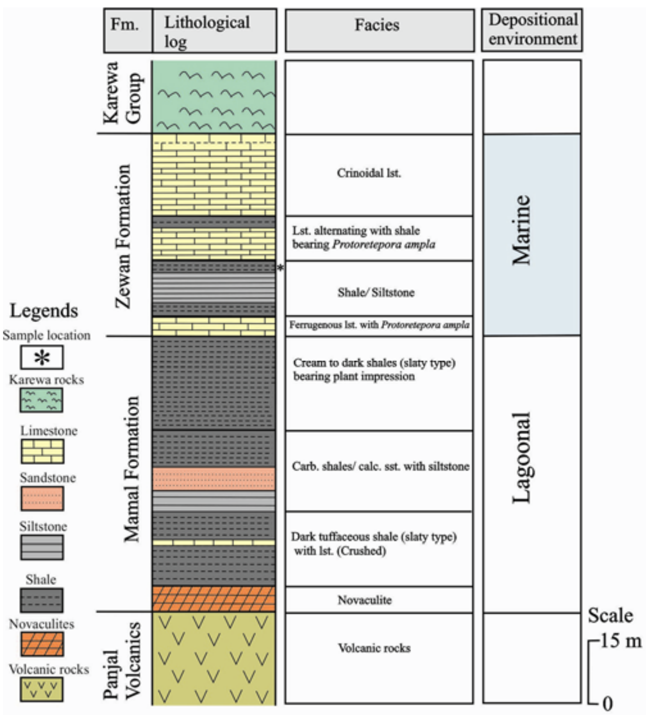

Figure 2. Profile of the Zewan Formation (type profile) exposed at Zewan spur, showing position of the charcoal bearing layer.

Bhat and Bhat[18] divided the rocks of Zewan Formation exposed at Zewan spur into three lithounits (A, B, C) and concluded that these rocks were deposited in marine fore-slope to platform depositional settings. Nakazawa *et al.*[10] suggested a shallow neritic environment for early stages of Zewan Formation.

Charcoal-bearing sediment from a dark gray shale of the Zewan Formation (Figures 1 and 2) was studied at the Setor de Botânica e Paleobotânica – Museu de Ciências Naturais, UNIVATES, with the aid of a stereomicroscope (Zeiss Stemi 2000 – C) with magnification between 10 and 40 times and is stored in the palaeobotanical collection under the acronym PbU. Samples which showed isolated tracheids with a silky lustre were subsequently mounted on standard stubs with adhesive tabs for anatomical analysis under a Scanning Electron Microscope (Zeiss EVO LS15) at the Parque Científico e Tecnológico do Vale do Taquari (Tecnovates) at UNIVATES.

The density of tracheid fragments on the samples surface was established with repetitive counts (five per sample) made in randomly distributed square plots (1.0 × 1.0 cm). All measurements were taken from calibrated images with the aid of the software package ImageJ[19].

On the surface of a dark-gray shale layer, and also within the entire 1.5–2 cm thick bed; numerous small, elongated (0.1–4.7 mm length; 0.2–2.0 mm wide) objects leap to the eye, due to their silky lustre, which is in contrast to the normal dull surface of the clay layer (Figure 3). Under the microscope these objects resemble isolated tracheids or tracheid fragments and under the SEM some anatomical details became obvious. The tracheids appeared mostly isolated and shattered, ranging from 32.8 to 100.2 μm in width (Figure 4 *a* and *b*). Homogenized cell walls are preserved (Figure 4 *c*) and biseriate circular pits (1.6–3.4 μm in diameter) on cell walls (Figure 4 *d*) could be observed.

Based on these features (silky lustre, preserved anatomical details, homogenized cell walls), all diagnostic for charcoal[20–22], we interpret these remains as charred

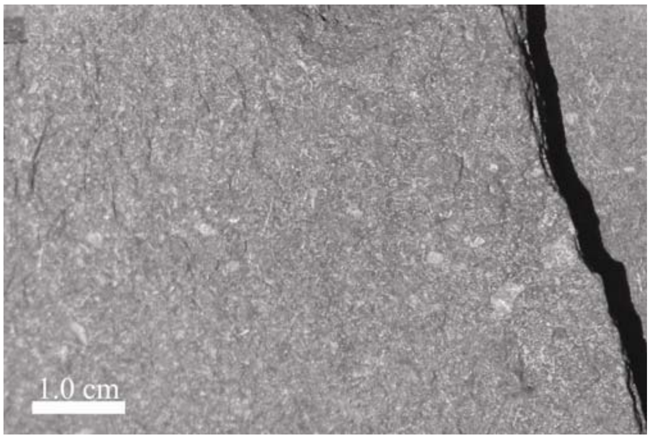

Figure 3. Macrophotograph of sediment with numerous isolated shiny tracheid fragments; scale bar = 1 cm.

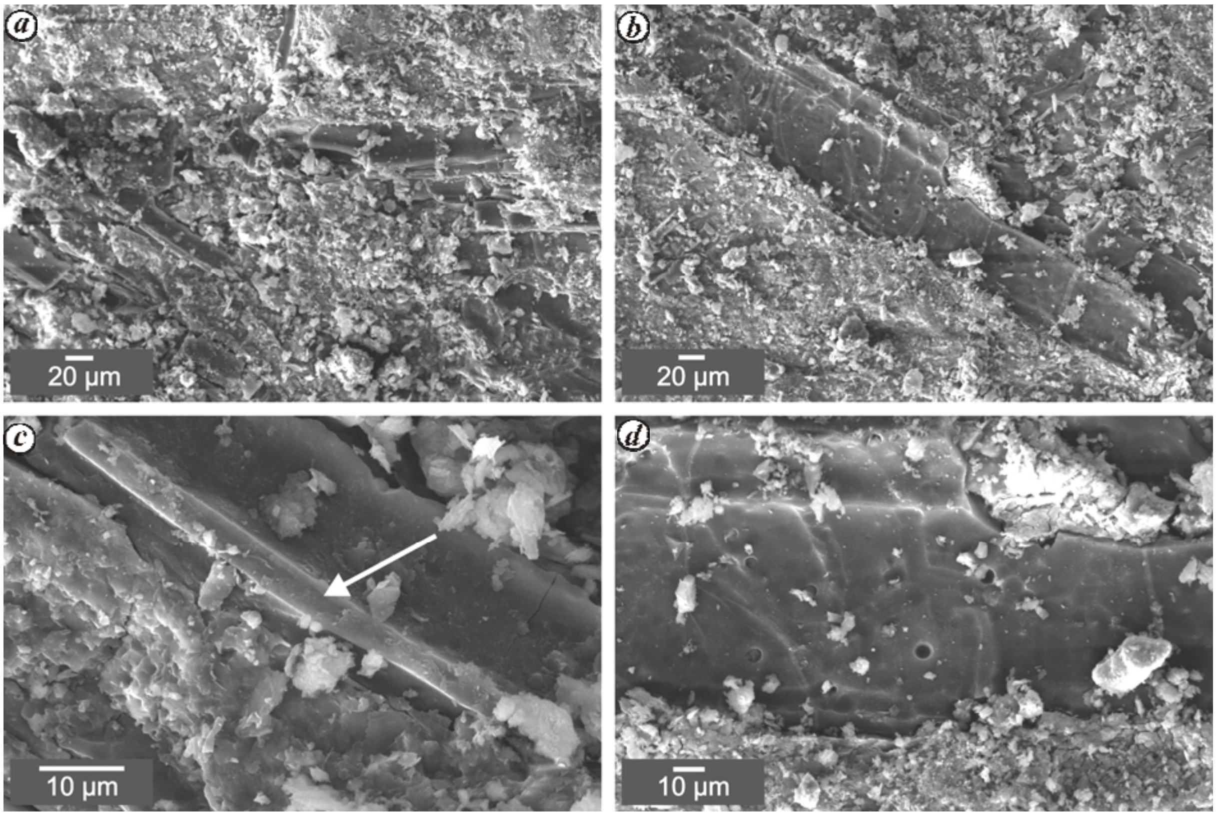

Figure 4. SEM images of charred fragments of tracheids. ***a***, Tracheid fragments within sediment, ***b***, Fragment of large tracheid in sediment, ***c***, Tracheid fragment exhibiting homogenized cell wall (arrow), ***d***, Enlargement of (***b***) with biseriate pits on tracheid wall.

fragments of tracheids. Such isolated tracheid fragments are produced during wildfires or through mechanical fragmentation of larger pieces of charcoal after a fire. Such meso-charcoals produced during fires can be transported over fairly large distances by wind or water transport and are usually considered in (palaeo-) environmental studies as evidence of wildfire on a landscape/watershed scale[23]. Similar occurrences of isolated charred tracheid fragments are not only known from studies on modern and Quaternary fires[24] but also from various pre-Quaternary sediments[25–27].

Due to the fragmentary nature of the tracheidal remains, nothing can be said about the taxonomy of the plants which burnt or the vegetation type which experienced wildfires during the Late Permian in the area from which the charcoals derived. However, the presence of these remains confirms the occurrence of palaeo-wildfires at the northern margin of Gondwana during deposition of the Late Permian Zewan Formation from where the charcoal was transported over a considerable distance into a marine environment. This gives further evidence to the globally wide-spread occurrence of wildfires during this period, as already evidenced by multiple records from Euramerica[28–30], Cathaysia[31,32] and Gondwana[3,4,7,33–37].

Though there are a considerably large number of reports from the Middle Permian, the reports on Late Permian macroscopic charcoal (six in total) are far from achieving the constantly increasing number of citations for the Gondwanan Early Permian[3]. The increasing aridity which occurred in many terrestrial palaeoenvironments from the Roadian onwards certainly influenced the Gondwanan palaeo-wildfires regime[6].

The preservation of a high number (up to 18 frag. cm^{-2}) of meso-charcoal in a distal depositional system shows that the fire regime on the continent was intense enough to provide high concentrations of charred bioclastic material. Despite the observed reduction in plant diversity[38], the extreme climatic conditions probably increased the frequency of fire events on the continent, which allowed for the accumulation of charcoal as observed in the material here studied.

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