FOSSIL WOOD FROM MIOCENE EPOCH (MANCHAR FORMATION, SINDH): RECONSTRUCTION OF PALEO-CLIMATE AND PALEO-ECOLOGY WITH THE HELP OF MORPHOLOGICAL AND STABLE CARBON ($\delta^{13}C$) ISOTOPIC STUDIES; COMPARISON OF CLIMATE WITH THE SAME AGE WOOD SPECIMENS IN THE WORLD

MUHAMMAD IMRAN

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Scholar's Name: Muhammad Imran Registration No. 01-262201-017

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DEDICATION

I dedicate my thesis to my beloved (Late) Father and Mother, for their efforts, prayers and for their hopes for my bright future

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In preparing this thesis, I was in contact with my many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Muhammad Iqbal Hajana, Senior Assistant Professor for his encouragement, guidance, critics and continuous support to achieve my objectives to work ^{13}C isotopic analysis for the very first time in Pakistan on wood Fossils collected from Ranikot area. It is also worth mentioning to thank my Co-supervisor, Dr. Noorulain Soomro, Professor, Institute of Plant Sciences, Sindh University, Jamshoro for her assistance, advice from thin section preparation to microscopic analysis and in identification of wood Fossils species. Without her support, it was difficult to authenticate the research results.

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ABSTRACT

Sedimentary docks are found worldwide and include a variety of fossils, including wood, plant, and invertebrate fossils, as well as imprints that provide insight into the planet's prehistoric climatic and geographical conditions. The petrified wood fossils collected from the Manchar Formation of Miocene in age, to reconstruct the paleo-environment Paleoecology of the area with help of morphological and stable carbon isotopic studies of $\delta^{13}C$. 115 fragmented wood fossil specimens collected from the study area buried into soil and exposed on the surface from the Manchar Formation. After careful examination, seven specimens probably the part of stem, clean and not weathered have been selected for the anatomical and isotopic studies. For the purpose of anatomical studies, three types of thin sections i.e. Transverse, Radial and Tangential were prepared. These 21 thin sections from seven wood fossils specimens were studied under simple Polarizing Microscope. On the basis of anatomical studies five species including four new wood fossils species reported from the study area. On basis of anatomical features, identified wood fossils species compared with the modern hard wood species. Seven pulverized wood fossils specimens sent to the Pakistan Institute of Nuclear Science and Technology (PINSTECH), Islamabad, Pakistan for (Solid-state Cross-Polarization Magic Angle Spinning Carbon-13 Nuclear Magnetic Resonance CPMAS $\delta^{13}C$ NMR analysis. Results of isotopic analysis of $\delta^{13}C$ ‰VPDB values are ranging from -22.16‰ to -28.35‰. With the help of the range of $\delta^{13}C$ ‰VPDB values specified for the C_3, C_4 and CAM plants, it is observed that analyzed wood fossils specimens belong to the C_3 plants. C_3 plants also referred as a “Temperate plants. Both anatomical observations and Carbon Isotopic analysis confirmed that Sindh had temperate climate during Miocene time and received sufficient rainfall with wet climate. Climate of Sindh has changed with the passage of time and became arid, desert and hot type.

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LIST OF SYMBOLS/ABBREVIATIONS

$\delta^{13}C$	-	Isotope of Carbon
YA	-	Years ago
Man	-	Manchar
RK	-	Ranikot
CPMAS	-	Cross-Polarization Magic Angle Spinning
^{13}C NMR	-	$Carbon^{13}$ Nuclear Magnetic Resonance
PNISTECH	-	Pakistan Institute of Nuclear Science and Technology
pCO2	-	partial pressure of Carbon dioxide
$\delta^{13}Cp$	-	Carbon Isotopic signature of product
$\delta^{13}CB$	-	Bulk organic matter
$\delta^{13}CR$	-	Respired Carbon dioxide
Ma	-	Million
PCIEs	-	Positive Carbon Isotopic Excursions
CLAMP	-	Climate Leaf-Analysis Multivariate Program
pCO_2	-	partial pressure of carbon dioxide
HPABZ	-	Hettigian-Pliensbachian assemblage biozone
GSP GARL	-	Geological Survey of Pakistan's Geosciences Advanced Research Laboratories
HDIP	-	Hydrocarbon Development Institute of Pakistan
IAWA	-	International Association of Wood Anatomists
r	-	Radial
t	-	Tangential
q	-	Transversal
h	-	High
me	-	Medium
mo	-	Modest
PDB	-	Pee Dee Belemnite
MAP	-	Mean Annual Precipitation
CAM	-	Crassulacean Acid Metabolism
VPDB	-	Vienna Pee Dee Belemnite
NLRs	-	Nearest Living Relatives

CHAPTER 01

INTRODUCTION

Ancient life is preserved in the Sedimentary columns all around the world in the form of various types of fossils (including Invertebrate and vertebrate fossils, wood fossils, plant fossils, and imprints) and revealed the pre-historic climatic and geographical conditions on Earth. Paleontology, Paleoclimatology and Paleogeography, Paleoanthropology, and Paleobotany are the major fields of science that elaborate the relations of past living organisms with their environment and their conditions. These million years old witnesses (fossils) are the indicators of age, past, and evolution. Today, with the help of this evidence of nature, scientists can reconstruct the past environment and climatic conditions, linking the primitive species of animals and plants with the present fauna and flora that live on Earth. These fossils help researchers to understand the extinction of animals and plant species, the effect of climate on animals and plants, the causes of their annihilation, and the modification in their anatomical structure due to climatic and environmental changes.

The scholar conducted the field work in the area of Ranikot, Jamshoro District, Sindh, Pakistan to collect petrified wood fossils from the Manchar Formation of Miocene in age, to reconstruct the paleo-environment Paleoecology of the area with help of morphological and stable carbon isotopic studies of $\delta^{13}C$ (Fig. 1.1). Approximately 115 fragmented wood fossil specimens collected from the study area buried into soil and exposed on the surface from the Manchar Formation. After careful examination, seven specimens probably the part of stem, clean and not weathered have been selected for the anatomical and isotopic studies (Fig. 1.1).

Rani kot group in the Sindh province has long been known as one of the most fascinating and classical areas, both geologically and paleontological. Petrified wood and plants fossils have been exposed in Laki Range, Kirthar province of Lower Indus Basin, Pakistan. Plant/wood fossils have been deposited in Miocene to Pliocene age rocks. The study of fossil wood and its distribution pattern has been a useful tool in interpreting the nature and type of vegetation, and the ecological conditions prevailing in the past geological periods. Thus it also serves as an important indicator of past geographical conditions. The presence of fossiliferous plant in the tertiary and quaternary rocks of Sindh was first time reported by Bland ford (1879), while he was dealing with the topography of Sindh locale. Pascoe (1963) stated the silicified dicot and monocot fossil woods in the upper tertiary and quaternary rocks of Sindh area. So far fossil wood which had been identified and depicted from Sindh, and other areas of Pakistan (Khan and Rehmatullah 1968; 1971; Khan et al., 1972; Khan and Rajput, 1976; Rajput and Khan, 1982; Rehmatullah et al. 1984 and 1984; Rajput, et al., 1985; Ahmed, et al., 1993; Bhutto et al., 1993; Ahmed et al. 2007a; 2007b; Shar. et al., 2007; Soomro et al., 2014; 2017a; 2017b). Fossils are significantly important to depict the pre-historic life.

Fossils are primarily found in sedimentary strata because the mode of formation of these rocks provides remains of animals and plants a favorable environment to preserve, unlike the igneous and metamorphic rocks in which heat and pressure elements are involved. Animals and plants trapped inside the Igneous and Metamorphic zones burnt due to excessive temperature and pressure and could not be preserved. There are three types of fossils that are found depending upon their biological origin.

i. **Vertebrate Fossils** (remains of vertebrate animals in the form of complete skeletons or fragments)
ii. **Invertebrate Fossils** (remains of invertebrate living organisms in complete form or in a small part)
iii. **Plants Fossils** (Wood Fossils, leaves imprints, Petrified wood Fossils, Mineralized Fossils)

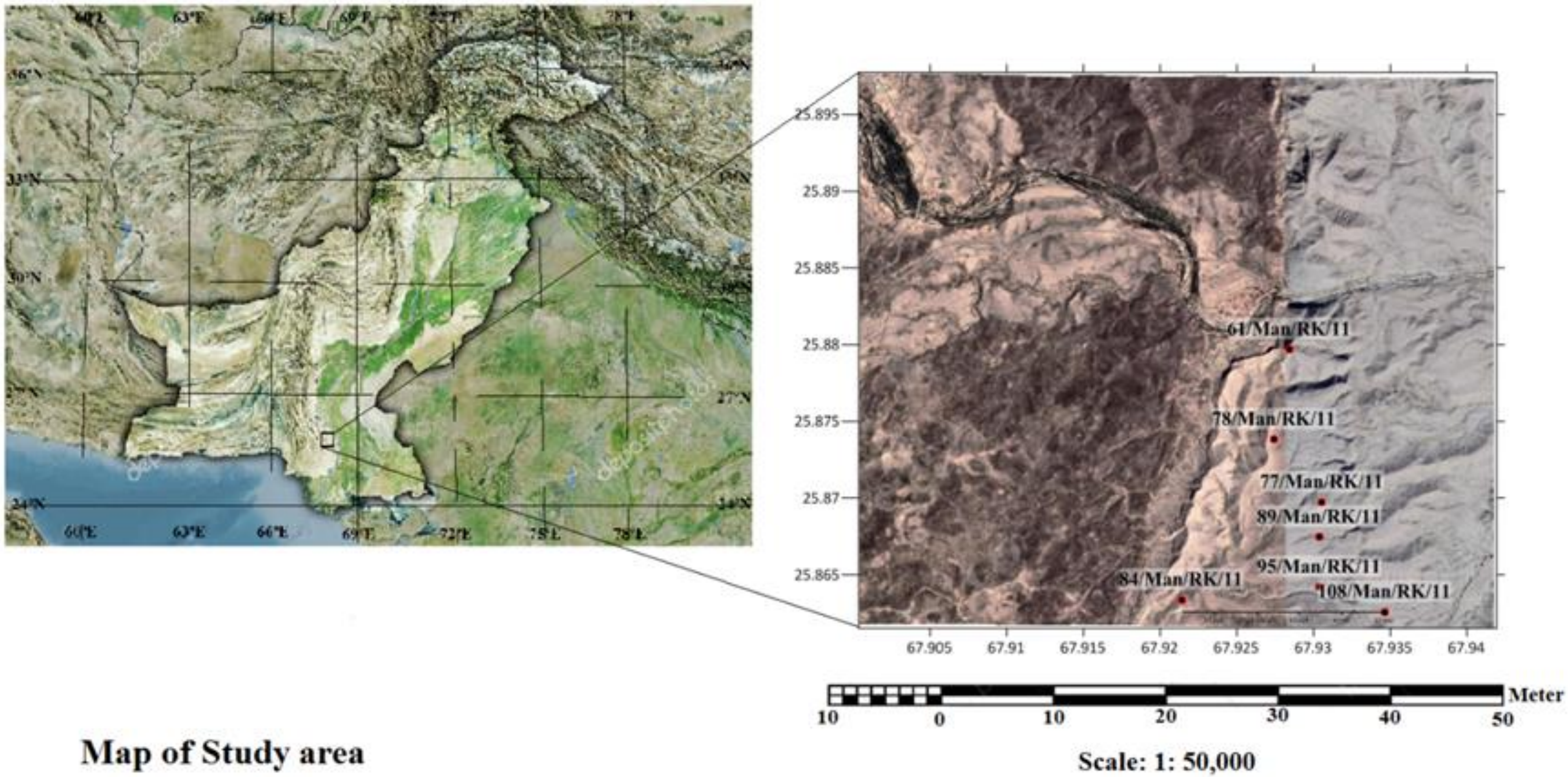


Figure 1.1 Map of study area, Manchar Formation (Miocene), Ranikot, District Jamshoro, Sindh, Pakistan

1.1. Conditions for the formation of fossils

Formation of fossils requires certain conditions to turn any organic organism into a fossil. It is necessary that any living species of animals or plants when die it quickly buried in an oxygen-free environment naturally by sediments like mud, sand volcanic ash, etc. to protect them from decomposing and decaying. Soft tissues of animals and plants decomposed swiftly due to the rapid bacterial action, leaving behind hard bones or shells. Complete organisms only preserved only under certain conditions. When remains of animals or plants are buried and more sediment is piled up on them, sediments seep into the pores of bones of animals, or the tissues of plants and makes them "lithified" with time and turns them into hard stone-like structures. The natural phenomenon of erosion breaks down the rocks holding remains of flora and fauna fragmented into pieces and reveals the history. Soft Tissues are only preserved under certain conditions or environments. When animals or plants are submerged in the ice cover it protects the specimen from bacterial action and provides an Oxygen-free environment. The best example of such preservation is "Yuka" the best-preserved woolly mammoth and Baby "Lyuba" discovered from Siberia and 39,000 YA and 42,000 YA old respectively{Matysová, 2016 #148}.

1.2. Types of Fossil Formation

{Matysová, 2016 #148}Depending upon their mode of formation, nature, and behavior, remains of organic life fossilized in the following ways;

1.2.1. Permineralization

Permineralization occurs when mineralized water solutions penetrate the soft tissues of plants and animals and turn them into the "stones" commonly referred to as **“Petrified”**. Commonly teeth, bones of vertebrates, shells of invertebrate fauna, and wood are preserved in this form.

1.2.2. Impression

If organisms' remains completely decomposed and removed by the action of underground water leaving behind empty spaces termed as a "Cast". When these empty spaces are filled with sediments or sometimes with minerals and form a complete shape of the decomposed organism called "Mold" {Matysová, 2016 #148}.

1.2.3. Carbon films

Animals in which a hard skeleton is absent and plants when buried under fine sediments, due to the time, pressure smashes the organic substance which allows the liquids and gases to escape and only a thin film of Carbon left behind on the surface of the specimen. Carbon film fossils are normally present in black shale. Carbon film fossils typically formed from fishes, crustaceans, and plants.

1.2.4. Preserved remains

Occasionally, remains of organic life are preserved completely or as a part with little modification. Medium is required to preserve the animals or plants completely or in a portion such as Ice, amber-hardened resin, tar, and sap, of ancient trees.

1.2.5. Trace fossils

Trace fossils or ichnofossils provide an indirect record of the biological activity of ancient life forms. Sometimes, the bodies of animals and plants are not preserved in soft sediments but the left behind impression of features of living organisms are called "Trace fossils". Worm burrows, Gastroliths (highly polished stomach stones used by extinct reptiles for grinding food), and food grains provide valuable information regarding past life feeding habits. (Gingras et al., 2007).

1.3. What are wood fossils?

Wood fossils, also recognized as "Fossilized trees", are the well-preserved part of the plants which could easily be found. Not all the wood fossils need to become petrified. Only a portion of the plants is preserved and the rest of the part is completely remaining unidentified. That is the reason that the plant contains a particular type of botanical name as a suffix which usually includes "*xylon*" and a term that represents its apparent similarity with modern species. For example, wood fossils resemble the modern species "*Araucaria*" named "*Aracaryoxylon*" and wood fossils have similar features to the recent species "*Arechaeacea*" which is called "*Palmoxylon*" etc.

Wood fossils are found at numerous localities in many places of the world and characterize the presence of ancient forests of all ages from 380 million years old Devonian period fern tree forests to the presence of only a few million years old modern species of hardwood and conifers forests.

Millions of years before stem wood of plants submerged in the wet sediments soaked with highly concentrated mineral solutions. Due to the absence of Oxygen, the decay of the wood became slow and permitted the minerals to replace the organic matter of cell walls and fill empty spaces in the wood. Wood is mainly composed of holocellulose (cellulose and hemicellulose) and lignin which are completely replaced by mineral solutions and turned into stone. These are called “Petrified wood Fossils”.

1.3.1. Types of wood fossils

Depending upon their mode of formation, there are three types of Wood Fossils;

1.3.2. Petrified Wood

Petrified comes from a Greek word that means "rock" or "stone". Petrified fossils form when, with time all the organic matter of plants and cells is replaced by mineral solutions. In this process, the original structure of plant anatomy is maintained{Matysová, 2016 #148}.

1.3.3. Mummified Wood

In this process, ancient wood is not affected by mineral solution and does not seep into the cells or soft tissues of the plant. When trees are submerged in a dry, cold, or hot environment, they preserve the original structures of cells and tissues and provide valuable information regarding past environments and dendrochronology. These wood fossils are called Mummified Wood.Original tissues intact in Mummified wood due to the minimal changes in the cellular constituents (Mustoe, 2018). Due to the presence of original tissues up to millions of years of age and limitation of digenetic conditions necessary for petrification, Mummified wood is precious source of information about Paleoclimatic environment (Hook et al., 2015).

1.3.4. Submerged Forests

Submerged forests are the remains of trees that are sunken beneath the water of the bay, sea, ocean, lake, or any other form. Then, these remains are buried under mud, peat, or sand for thousands of years. These sediments become compact with time and provide an oxygen-free environment to these remains. The submerged forest holds a complete variety of flora and fauna.

1.3.5. Conditions for the Formation of Wood Fossils

- Based on essential elements that are important to the petrification process, Matysová (2016) illustrated a model for the conditions for the formation of wood fossils:
- Physical features of deposits
- Individual environmental conditions
- Availability of water, SiO_2, as well as additional minerals
- Temperature

- Pressure
- Fluid activity
- Mineral composition of sediments
- Genus of plant
- Tectonics (Bailey 2011)
- Time

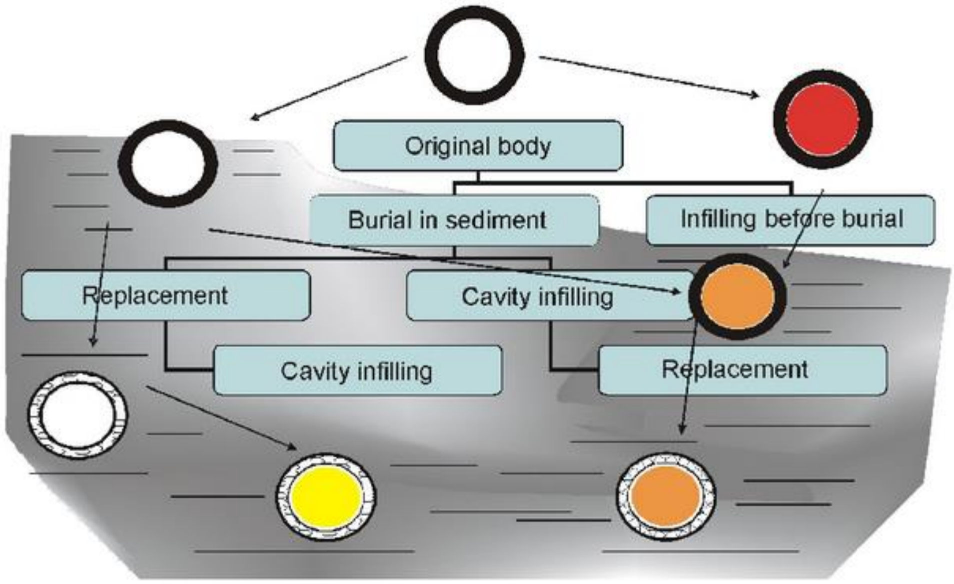


Figure 1.2 Model for petrification of wood Fossil (modified according to Petranek 1993)

1.4. Fossilization of Wood

Conversion of wood into a fossil is a complex process in which quite resistant organic structures generally consisted on cellulose, hemicellulose, lignin and all other components transform into fossils under different chemical and physical conditions and environments. Depending upon their mode of formation, there are two types of fossilization of wood: **Carbonization** and **Petrification**.

1.4.1. Carbonization or Coalification

Carbonization or Coalification is a complex process in which, due to the biochemical and geochemical manners Peat, lignite, coal, and anthracite originate. This process occurred in semi-humid to humid environments. Another carbonization occurs during volcanism when flowing lava thermally alters the rest of the wood on the surface except the root. This results in the formation of natural coke. In this manner, plant anatomy is entirely vanished, and simply the external morphology of a root is restored. A slightly different process from carbonization is Charcoalification. In this method due to wildfire wood turned into charcoal.

1.4.2. Permineralization

(Taylor et al., 2009) The next common method is the fossilization of plant substance by a variety of minerals (Buurman, 1972). Taylor et al. (2009) characterized petrifaction and Permineralization as two distinct processes (Fig. 1.2). The terminology "petrified wood" is used in preference to "permineralized wood"(Mustoe, 2018).In Petrification, minerals fill the cell walls incompletely. In Permineralization, organic matter is completely replaced by minerals.

The process of Permineralization is named after a particular sort of mineral materials (Table 1.1).

1.4.3. Silicification

Silica-rich groundwater mineralized the wood that has become silicified, which is generally found in permeable rocks(Buurman, 1972). Then process of Silicification could take place in both types of wood buried in situ and transported from other areas before burial. A humid climate is more appropriate for the transportation of silica for the process of silicification (Kraut, 1933). In arid regions, silicified wood is frequently found in large amounts{Matysová, 2016 #148}.

1.4.4. Calcification (Carbonatisation)

In seasonally dry (arid) conditions, this Permineralization route is rather prevalent. (Matysová, 2016), the production of coal balls is one particular type of calcification. The preservation of structure is heavily reliant on crystallization. The wood structure may be well retained in cases where the crystals have not grown outside of the cell walls, but there is very little wood structure visible in parts that have recrystallized. (Buurman, 1972).

Table 1:1 Mineralization types of petrified wood (modified from (Matysová, 2016)

Group of Mineral	Minerals	Selected Publications
Silica and silicates	Opal, hyalite, tridymite, moganite, laumontite, quartz	Skoček (1970), Buurman (1972), Rex and Scott (1987), [1], [2], [3], [4], [5], Dietrich et al. (2001, 2013, 2015), Sweeney et al. (2009), Luthardt et al. (2016)
Carbonates	Calcite, aragonite, dolomite, siderite, malachite/azurite	Snigirevskaya (1972), Rex and Scott (1987), Brown et al. (1994), DiMicheleand Phillips (1994), Falcon-Lang and Scott (2000),

		Min et al. (2001), Scott andCollinson (2003), [1], [4]
Sulfides	Pyrite/markasite, cinnabar, galena, chalcopyrite, bornite, covellite	Kenrick and Edwards (1988), Garcia-Guinea et al. (1998), Butler and Rickard (2000), Grimes et al. (2002), Liu et al. (2002), Yamanaka and Mizota (2002), Strullu-Derrien et al. (2014)
Phosphates	Ca-phosphate, apatite, phosphorite	Skoček (1969), Buurman (1972), Sweeney et al. (2009)
Sulfates	Barite, gypsum, celestite	
Iron oxides and hydroxides	Hematite, limonite, goethite, lepidocrocite	Skoček (1969), Buurman (1972), Sweeney et al. (2009)
Fluorides	Fluorite	Götze and Rössler (2000), Witke et al. (2004), [4], Luthardt et al. (2016)
Miscellaneous	Sapperite, pitchblende, coffinite, calcium-oxide	Min et al. (2001)

1.4.5. Phosphatisation

Wood phosphatization is comparable to silicification but occurs less frequently. Matysová, P. (2016). Phosphatized wood was reported from the Pacific Seafloor (Goldberg and Parker, 1960). Phosphate may precipitate directly in wood or from fluids moving in the near-surface sediment layers in the cooler waters at the base of the (lake) basin. Phosphatized wood, fish bones, and apatite coprolites are all present in the lacustrine environment (Skoček 1969).

1.4.6. Fluoritisation

Wood from volcanic environments in the German town of Chemnitz has been reported to have undergone Permineralization by minerals like CaF_2 (Götze and Rössler 2000, Witke et al. 2004, Luthardt et al. 2016).

1.4.7. Pyritisation and Goethitisation

(Kenrick and Edwards, 1988) reported the presence of pyritized axes in the plants of Lower Devonian. In 1988, (García Guinea and Martínez Frías, 1998) also discovered the addition of pyrite in wood fossil cells. After performing Sulfur isotopic analysis and using SEM (Yamanaka et al., 2002) observed pyritisation in silicified wood. (Mustoe, 2018) also noted the pyrite inclusion in wood fossils. The same variables affect mineralization processes regardless of composition: pH, Eh, burial temperature, and the availability of dissolved elements. Anatomical characteristics and the wood's permeability are important factors in determining mineralization. When precipitation happens in multiple periods, the mineralogy of fossil wood may be complicated(Mustoe, 2018).

1.4.8. Manganisation

Although manganese hasn't typically been listed as a key element in fossil wood, it has occasionally been discovered that mixes of iron and manganese oxides have been identified in ancient wood (Mustoe, 2018). Inclusion of Magnesium in wood fossils cell structure depends upon the environmental conditions of the area and sediments in which wood buried.

(St. John, 1927)studied 25 thin sections of wood fossils under a light microscope after treating them with a solution of one-third Hydrochloric acid and two-thirds alcohol to remove silica from the pulverized powder. The analysis revealed that only a limited number of samples hold a complete fraction of anatomical features of wood fossils without silica.

(Sigleo, 1978), studied 200 Ma old *Araucarioxylon arizonicum* specimen to analyze the traces of original materials into the prehistoric specimen. Results of his research discovered that only insignificant quantity of traces of fossils persist after many millions of years. Overall research proposed that there is a rare chance for restoration of original organic matter in wood fossils.

1.5. Significance of Study of Wood Fossils

As the traces of the past, fossils are invaluable for author comprehension of the early geological processes and the development of plants and animals on Earth (Steno, 1667, Cuvier, 1796, Darwin, 1859). They offer distinct information for reconstructing events and situations that are not repeatable exactly, as well as natural, irreversible processes (Rößler et al., 2021).A naturally self-explanatory source of information on extinct biodiversity and paleoenvironments is found in wood fossils. An rise in the amount of fossil wood records from Tertiary and Cretaceous layers advances author knowledge of the patterns of anatomical specialization over geological time (Poole, 2000). This data helps in understanding the environmental changes. Researchers studying the anatomical structures of wood fossils can understand the past climate and compare the features with the modern species of plants and trees. Nowadays, scientists are using modern techniques such as isotopic studies to determine the age and to reconstruct the past environment. Isotopes of ^{13}C and ^{18}O provide accurate and authentic information about the past climate.

1.6. Present Research

Seven specimens of wood fossils from Manchar Formation, Rani Kot Fort, Jamshoro District, Sindh, belongs to the age of Miocene-Pliocene have been selected with the following aims to be carried out in author research;

a) To reconstruct the Paleo-climate and Paleo-ecology of the study area with the help of isotopic studies of Carbon (^{13}C) and anatomical studies of wood fossils.

b) To discover and analyze fossil wood from Rani Kot Fort, District Jamshoro, province Sindh Pakistan, belonging to Manchar formation.

c) To determine the external and internal structure of the plant fossils to assimilate it with living species.

d) Using the body of accessible research as a guide, compare the Paleoclimate and Paleoecology of the Manchar Formation, located near Rani Kot Fort, Jamshoro, Sindh (Pakistan), with those of other formations from the same age around the globe.

1.7. Area of Study

The area of study is located ~108 km away from North-West of Jamshoro District, 121 km from Hyderabad city via Rani Kot Fort Road, Indus Highway/N-55 and 4.4 km from Rani Kot Fort, Sindh via Ranikot Fort Road. The area of study is shown in the satellite mosaic map (Fig.1.2) with the coordinates in Table. 1.2.

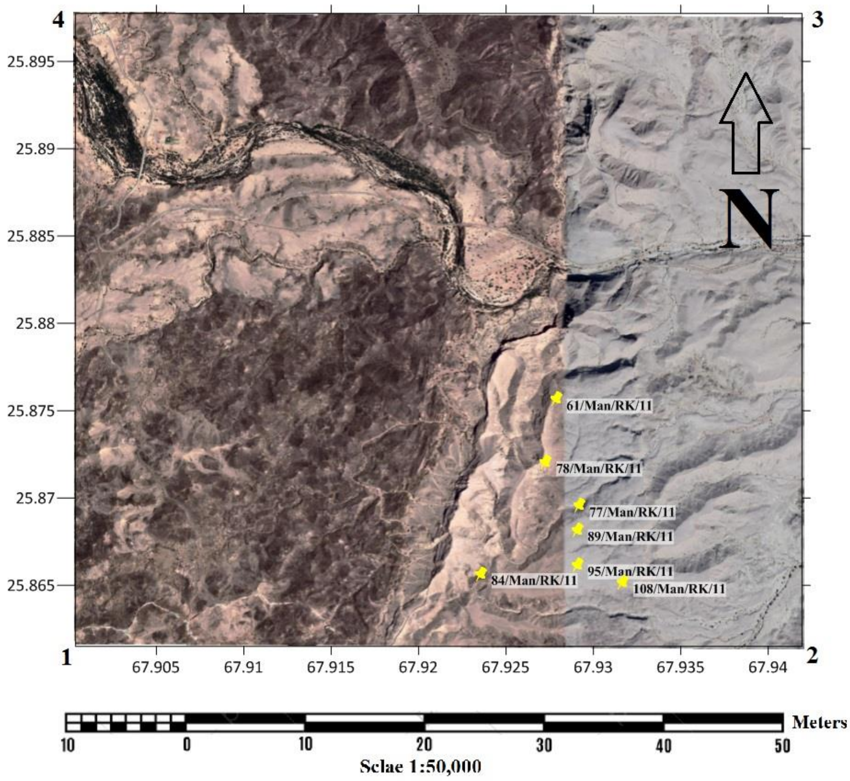


Figure 1.3 Satellite map of the study area along with sample locations

Table 1:2 Coordinates of the map of the study area

Sr. No.	Latitude	Longitude	UTM Easting	UTM Northing
1.	25.86151	67.90036	389818	2860808
2.	25.86145	67.94193	393983	2860767
3.	25.89774	67.94115	393937	2864787
4.	25.89774	67.90036	389851	2864821

Geology of the Study Area

Drawing from paleontological evidences, geology of the study area comprised on rocks sequences from Paleocene to Pliocene in age. This includes Ranikot Group (Paleocene), Sohnari Formation (late Paleocene) which is unconformabley lies over Laki Formation (Eocene), Laki Formation (Eocene) and Manchar Formation (Miocene to Pliocene in age).

Hunting Survey Corporation (HSC) conducted detailed geological survey in the area in 1960 for the mapping the area and reported the following geological sequences in the area (Fig. 1.3) and (Table 1.3.);

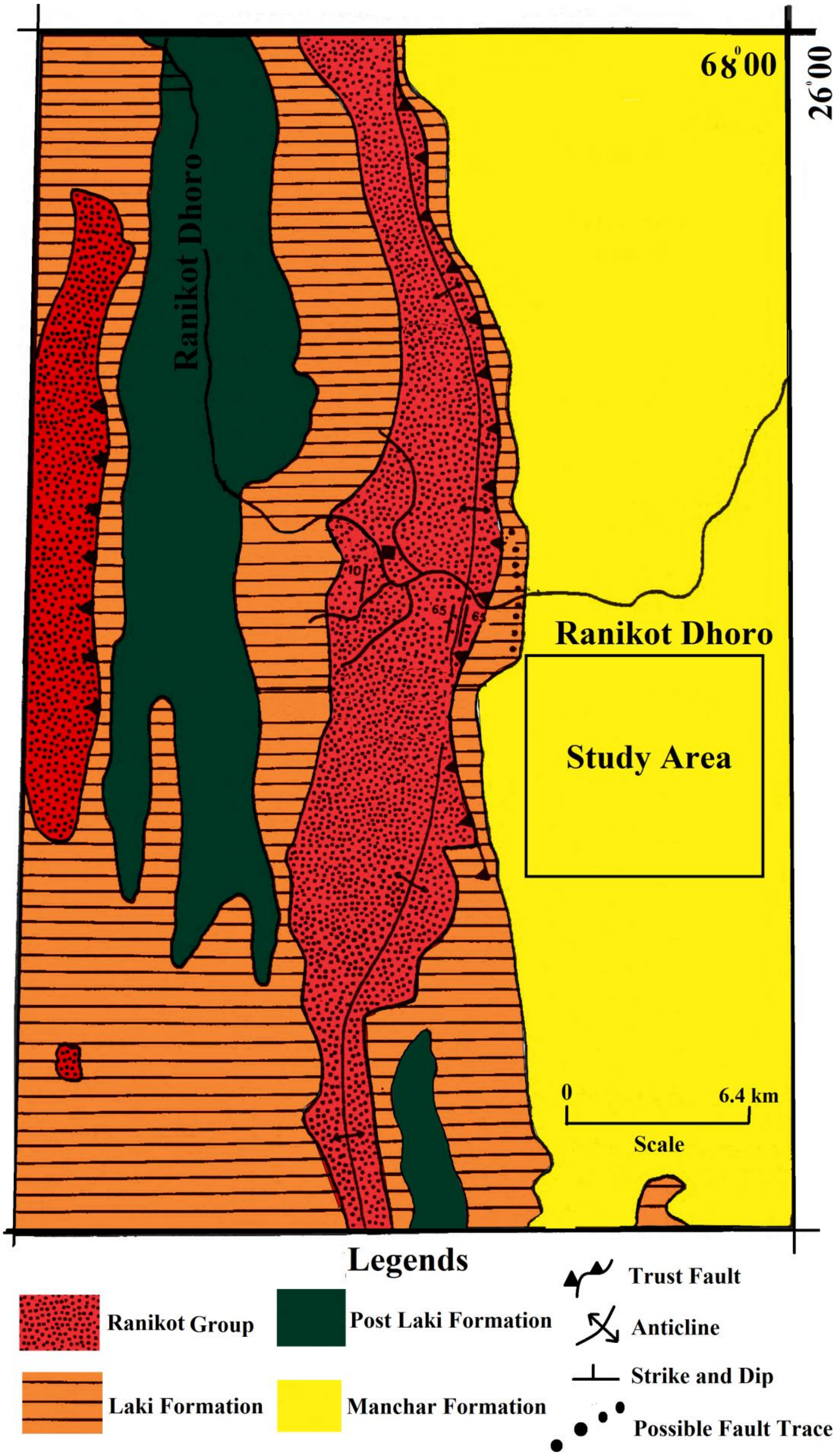


Figure 1.4 Geological map of Ranikot area (Wnuk et al., 1993)(Modified after (Khan et al., 2017)

Table 1:3 Generalized Stratigraphic sections exposed around Ranikot Fort area

Formation		Age	Type Section
Manchar Formation		Miocene to Pliocene	Geological sections near Lake Manchar(Raza et al., 1984b)
Laki Formation		Early to Middle Eocene	Mari Nai Southwest of Bara Nai(Kureshy, 1984)
Sohnari Formation		Early Eocene	Southern Indus Basin in Pakistan (Hakro et al., 2018)
Ranikot Group	**Lakhra Formation**	Late Paleocene	Lakhra Village, northwest of Hyderabad in Sindh Province(Raza et al., 1984b)
	Bara Formation	Early Paleocene	Bara Nai/Nala Lat. 260 07’ 06’’N; Long. 670 53’ 12’’ E (Malkani and Mahmood, 2017)
	Khadro Formation	Early Paleocene	Bara Nai/Nala Lat. 260 07’ 06’’N; Long. 670 53’ 12’’(Malkani and Mahmood, 2017)

1.8. Ranikot Group

First time, Blanford (1876), used term of “Ranikot Series” or “infra-Nummulitic” to differentiate the lithological units present between the Pab Sandstone (late Cretaceous) and early Eocene Laki Series which consist on limestone and shale in the lower Indus basin(“Kirthar or lower Nummulites group” of Blanford)(Rage et al., 2014). For the very first time, Blanford (1876) used the name of “Ranikot Group”, instead of name of the Rani kot Fortress (Asghar et al., 2021). (Vredenburg, 1909)further split "Rani Kot Group" into "Upper Ranikot (limestone)" and "Lower Ranikot (sandstone)."(Asghar et al., 2021). The Ranikot Group is made up of the Khadro, Bara, and Lakhra formations, three separate lithostratigraphic units arranged in increasing order. (Barry et al., 2013), but (Frederiksen, 1994)incorporated the Sohnari formation in this group (Frederiksen, 1994; Merle et al., 2014). The Sangiali Group is replaced in lower Indus Basin by Ranikot group named by Ranikot (Lat. 250 54’ 24’’N; Long. 670 54’ 38’’ E) including the Khadro, Bara and Lakhra formations (Malkani and Mahmood, 2017). The Sagiali Group in Middle Indus Basin is also Paleocene in age and equivalent to the Ranikot Group in Lower Indus basin. Ranikot group consisted on variegated sandstone, shale, limestone, volcanic basalt, intrusions, veins of gypsum, and some content of coal and presence of fossils. The drilling revealed that it has the maximum thickness at Sann back well east of Thano bulla Khan which is (3,300 ft.). Ranikot is totally absent at Mari North east of Rohri probably due to uplifting.

1.8.1. Khadro Formation

The term “Khadro” proposed by (Williams, 1959). These are the old Paleocene rocks in Sindh. Khadro Formation is Paleocene in age. The Carditabeaumonti beds of Blanford (1878), the Venericardiashales of Eames (Eames, 1951), the Bad Kachu and Thar formations of HSC (1961), the basal portions of the Karkh, GidarDhor, and Jakker groups(Malkani et al., 2017).According to Cheema and colleagues (1977), the Khadro Formation is 140 m thick in the Lakhra Anticline and 67 m thick at its type region, KhadroDhoro in the Lakhi Range (Wnuk et al., 1993).It is composed of volcanic, shale, sandstone, and limestone. Igneous rocks such as Deccan trap basalts can be discovered in the subsurface drill hole and in the oldest Paleocene Khadro formation in the Kirthar basin, which is exposed in the Laki range(Hon, 2010).Its higher contact with the Bara Formation is transitional and conformable, whereas its lower contact with the Vitakri Formation is disconformable. It is the oldest known Paleocene age (Malkani and Mahmood, 2017).

1.8.2. Bara Formation

Ahmed and Ghani named it as “Bara Formation” (Written communication in 1971 to Cheema et al. 1977) after Bara Nai (Lat. 260 07’ 06’’N; Long. 670 53’ 12’’ E, Type section) of Laki Range(Malkani and Mahmood, 2017).Its principal reference section is Ranikot (Lat. 250 54’ 24’’N; Long. 670 54’ 38’’ E)(Malkani and Mahmood, 2017).Bara Formation 450m thick in the type locality at Bara Nai. It is mostly made up of coal, shale, siltstone, and sandstone. Most detrital rocks are pyritic and carbonaceous, but certain strata of detrital rocks are calcareous, glauconitic, burrowed, and shelly in different proportions(Frederiksen, 1990).According to early scholars, the Bara Formation (also known as "Lower Ranikot") is primarily composed of non-marine to brackish water deposits (Frederiksen, 1990). It looks that the Bara Formation and the Lakhra Formation have conformable contact (Frederiksen, 1990).The Bara Formation contains few fossils, and its age is not entirely certain. Palynological data point to a mangrove swamp, shallow marginal sea paleoenvironment (Frederiksen, 1994)(Charbonnier et al., 2013). (Frederiksen, 1990), described that Planktic foraminiferal evidence supported by pollen data indicates that the Bara-Lakhra-Sohnari sequence as a whole is late Paleocene in age.

1.8.3. Lakhra Formation

Ahmed and Ghani proposed the name of Lakhra of Laki Range (Written communication in 1971 to Cheema et al. 1977) after Lakhra of Laki Range(Malkani and Mahmood, 2017). Its’ type section is in Lakhra Village, northwest of Hyderabad in Sindh Province(Raza et al., 1984a). The interface above between the Bara Formation and the Lakhra Formation appears to be conformable and gradational in some places (Outerbridge et al., 1991). However, there is evident nonconformity due to erosion in multiple areas of the Lakhra Dome (Charbonnier et al., 2013). The major writers refer to the Lakhra Formation as "Upper Ranikot." It appears that the deposition there is primarily shallow marine to brackish water. This formation is extensively exposed in the Lakhra Dome near Jhirak, where E.W. Vredenburg gathered and published a large collection of fossilized mollusks (Cossmann, 1909). The Lakhra Formation has some carbonaceous bends similar to the Bara Formation, but its unique rocks are shell hash beds, marl, and foraminiferal limestone. Shale makes up the majority of the Lakhra Formation, which is substantially more glauconitic and calcareous than the Bara Formation. Compared to the Bara, the Lakhra was deposited in a deeper marine Palaeo environment, maybe in front of some mangrove swamps(Charbonnier et al., 2013).Its age is Late Paleocene (Malkani and Mahmood, 2017).

1.8.4. Sohnari Formation

Vredenbergsub-divided Laki Group in various members and designated it as a "Basal Laki laterite /Sohnari Member. It was named by Outerbridge et al (1989) for the basal Laki laterite (8m) of Nuttal (1925) and after the Sohnari member of HSC (1961)(Malkani and Mahmood, 2017).Later on, it was declared as a "Formation" due to the change of other laterites names as Dilband Formation (J/K boundary) by Abbas et al (1998), Vitakri Formation (late Cretaceous in age at K/T boundary by Malkani (2009). Sohnari Formation commonly consists on lateritic clay, shale, sandstone, arenaceous limestone and lignite coal seems (Malkani and Mahmood, 2017). The Sohnari formation consist of 65% of shale, 21% of sandstone with lesser amount of 6% of siltstone and minor amount 1% of mudstone and conglomerate (SanFilipo et al., 1992). Sohnari Formation has disconformable contacts with lower Lakhra Formation and upper Laki Formation (Malkani and Mahmood, 2017). On the basis of pollen data which support foraminiferal evidence (Frederiksen, 1990) suggested the age of entire Bara-Lakhra-Sohnari sequence late Paleocene. Later on (Malkani and Mahmood, 2017)declared its age as early Eocene.

1.8.5. Laki Formation

Laki Formation covers the Ranikot Group, which Noetling (1903) also named the Laki Series for the lower half of Blanford's (1876) "Kirthar Series". Later on it is redefine as “Laki Group” by Hunting Survey Corporation (1961) (Brohi et al., 2012). Cheema et al (1977) termed Laki Group as Laki Formation (Siddiqui et al., 2022). (Nuttall, 1925) proposed following divisions in Laki Series (Table 1.4);

Table 1:4 Division of Laki Series proposed by (Nuttall, 1925):

Sr. No.	Division of Laki Series	Thickness in ft.
i.	The Laki Limestone	200 to 600
ii.	The Meting Shale	95
iii.	The Meting Limestone	140
iv.	The Basal Laki Laterite/ Designated as “Sohnari Member/ Formation	25

With trace levels of marl and inferior shale, limestone makes up the majority of the Laki Formation. (Malkani and Mahmood, 2017). Métis described its stratigraphy that at the top white to creamy-white rubbly bedded limestone with alternating calcareous shale and marl(Métais et al.). Noetling (1905), Nuttal (1925), Davis (1925), Haque and Khan (1956), Haque (1962a), Hunting Survey Corporation (HSC) (1961) and Iqbal (1973) reported that the Laki Formation is richly fossiliferous and contains fossils of foraminifera, gastropods, bivalves, echinoids and algae(Malkani and Mahmood, 2017). At individual outcrop level, (Frederiksen, 1990) claimed that there is no unconformity between the Sohnari Member of the Laki Formation and the Lakhra Formation. (Métais et al.) Confirmed that basal Limestone Member overlies Sohnari

Formation has a sharp confirmable contact. On the basis of fossils discovered from Laki Formation, its age assumed from Early Eocene to Middle Eocene(Malkani and Mahmood, 2017).

1.8.6. Manchar Formation

The rich fossiliferous Manchar Formation is exposed in the badlands south of the Sehwan Sharif in Sindh (Zijlstra et al., 2013). Blanford (1879) originally described the Manchar Formation which is extensively exposed around Lake Manchar, along the sideways the base of the Kirthar Range and its considerable portions between Kirthar Range and Indus River (Raza et al., 1984a). Blanford, 1833; Williams, 1959; Hunting Survey Corporation, 1960; and **Pascoe, 1964 termed Manchar Formation in North-South outcrop as a "Siwalik"**, "Urak" or "Sibi" Group on the basis of molassic facies discovered from the outcrop (Raza et al., 1984a). For certain sections of the Manchar Formation, Cheema, Raza, and Ahmed (Shah,1977) additionally utilized the formational names "Dhok Pathan" and "Nagri."(Raza et al., 1984a). It is 2200 meters thick in the Gaj River portion (Khan et al., 1984), whereas it is 1000 meters thick in Sehwan (Pilgrim, 1912) (Malkani and Mahmood, 2017).(Jagirani et al.) Studied the Manchar Formation in well exposed area of Kari Bugti Section; Northern Laki Range, Southern Indus Basin, Sindh, Pakistan. (Jagirani et al.) Measured the thickness of Manchar Formation at Kari Bugti Section which is ~ 1055m thick and Miocene to Pliocene in age. According to research by Jagirani et al. (2020), the Manchar Formation has six distinct river depositional environments, ranging from coarse-grained flat-bedded sandstone to fine, Sandstone facies that are conglomerate and agglomerate, coarsely grained through the cross-bedding, and sufficiently Shale facies, clay facies, and mudstone and mudstone facies(Jagirani et al.) (Fig.1.4). The Manchar Formation was split into a "Lower Manchar" and a "Upper Manchar" by Blanford (1879). Lower Manchar mainly consists on gray sandstone while "Upper Manchar" composed of conglomerate and inferior sandstone atop orange and brown silts. (Raza et al., 1984a). Many authors reported vertebrate and invertebrate fossils and wood fossils from this unit of Manchar Formation. (Raza et al., 1984a) carried out thorough investigations to look at the Section's Miocene vertebrate fauna and geology, and several species were found. They have reported that Manchar Formation holds the first record of South Asian presence of *Conohyus, sindiense, Listrodonpentapotamiae, Dorcatherium,* and *bovids* and thus records establishment of the classic Siwalik faunal suite (Raza et al., 1984a). It unconformably lies over Laki Formation (Jagirani et al.). Manchar Formation contains large assemblage of petrified wood fossils of Miocene to Pliocene age.

1.8.7. Significance of Manchar Formation as a (Siwalik Group)

Based on molassic facies seen in the outcrop, Pascoe, 1964 referred to the Manchar Formation in the North-South outcrop as a "Siwalik," "Urak," or "Sibi" Group (Raza et al., 1984a). {Hakro, 2024 #149} also termed Manchar formation in the Southern Indus Basin as a Siwalik Group. {Raza, 1984 #150} discovered new fauna in the Manchar faunas include a **large hominoid** and another small primate, two creodonts, three *amphicyonids*, a shovel-tusked *amebelodontine,* a *chalicothere*, species of *Orycteropus, Zygolophodon, St egolophodon*, and *Brachyodus*, a species comparable to *Tetraconodon* minor, two small species of *Dorcatherium*, and a *palaeomerycid*. {Raza, 1984 #150}suggested that It is evident that the transition from the Bugti type of fauna to that found in the basal Manchars is what gave rise to this unusual and distinctive Siwalik fauna. Of the Chinji species, about 25% are directly connected to the Bugti taxonomy, with the remaining species most likely being immigrants. On the basis of relative age, faunal composition Manchar formation could be relate to the Kamlial, Chinji, Nagri and Dhok Pathan formations of Siwalik Group and could be consider as a part of Siwalik Group.

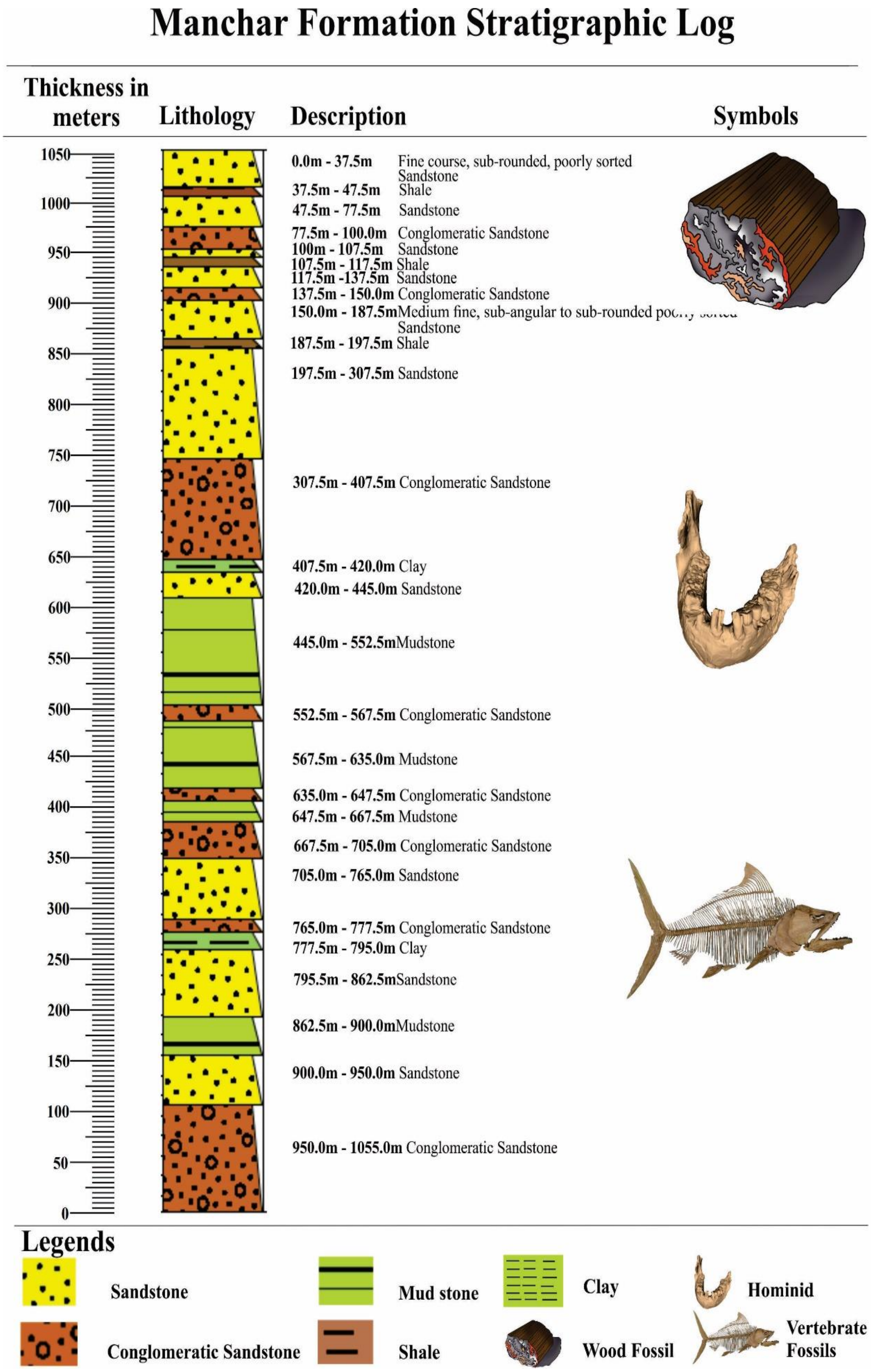


Figure 1.5 Manchar Formation Stratigraphic Log at Kuri Bugti Section, Northern Laki Range, Southern Indus Basin, Sindh (Modified after (Raza et al., 1984a)

1.9. Research Gaps / Research Problems

No $\delta^{13}C$ isotopic study literature related to the wood fossils of Manchar Formation is available on national level which is the clear indication that no work so far has been done on this aspect in our country. While on International level many researchers carried out $\delta^{13}C$ isotopic study on fossil wood and on leaves to reconstruct the Paleo-climate and Paleo-ecology.

1.10. Objectives

To achieve these aims following objectives are set;

a) $\delta^{13}C$ Isotopic study on wood fossils from Manchar Formation (Miocene age) exposed at Rani Kot Fort, District Jamshoro, Sindh by examining its chemistry with CPMAS ^{13}C NMR (Solid-state Cross-Polarization Magic Angle Spinning $Carbon^{13}$ Nuclear Magnetic Resonance (CP/MAS -NMR) will be carried out.

b) Three dimensional thin section studies will be performed to study the anatomical characteristics of the wood fossils.

c) Its morphology with light and electron microscopy will be studied.

1.11. Overview of Thesis

Seven Petrified wood fossils have been selected for anatomical and C_{13} studies which have been collected from the Ranikot area. Three types of thin sections are made from wood fossils for anatomical studies. Pulverized samples from specimens were sent to the Pakistan Institute of Nuclear Science and Technology (PNISTECH) ^{13}C. Based on ^{13}C and anatomical results Paleo-climate reconstructed. This research will not only be helpful in the reconstruction of the Paleo-climate and paleo-environment by using the authentic method of isotopic study but will also open new venues of research for other scientists to explore. It will be the beginning of an era in paleontology and in dendrochronology. This new initiative will help establish the relation between wood fossils and their past environment. With the help of this current research, the past environment of our country could also be compared with the past environment of the world with the same age.

CHAPTER 02

LITERATURE REVIEW

Organized study of fossilized wood remains buried in the Sedimentary strata of Ranikot, Thano Bola Khan, Kirthar ranges and its surrounding area has a significant role as an indicator in the botanical sciences for the interpretation of past vegetation and for understanding the distribution and evolution of ancient plants species through geological period. This study helps in the establishment of natural plant classification.

The anatomical structure of wood is commonly considered to be more conventional than the exomorphic features and therefore useful in the classification and restriction of the families and genera(Metcalfe and Chalk, 1950). (Rajput and Carolin, 1988) proposed that vascular characteristics are beneficial in the identification of taxa at species level, and in correcting the restriction (limitation) of species at different level of taxonomical order (Rajput and Carolin, 1988). Structural indications of fossilized wood are helpful in linkages of antiquity of certain families. The information obtained from morphological features may not form a reliable basis for phylogeny by itself, but if morphological features synchronized with Paleo-botanical indications, a better depiction of phylogeny of a taxon can be developed. When Blandford (1879) was studying the geography of the Sindh region, he made the first record of fossiliferous plants in the tertiary and quaternary rocks of that region. A Paleontology Laboratory was founded at the University of Sindh by Prof. K.M. Khan and he initiated the systematic studies of plant fossils occurring in the Tertiary deposits of Sindh. Following that, No investigation or attempt was made to identify these plant remains from this location until 1962. Numerous studies on the wood fossil species of this region were written by paleobotanists from this unbroken subcontinent and other parts of the world.

Among the outstanding contribution especially institution of new genera were those of (Boureau et al., 1950), (Chowdhury et al., 1960), (Chowdhury and Ghosh, 1946), (Chowdhury and Tandon, 1964), (Felix, J., 1883), (Ghosh and Culture, 1956)(Ghosh, 1960), (Ghosh and Ghosh, 1959), (Ghosh and Kazmi, 1961), (Mädler, 1939), (Navale, 1956), (Prakash and Barghoorn, 1961), (Prakash and Barghoorn, 1961; Prakash and Navale, 1962), (Ramanujam and Rao, 1966), (Schönfeld, 1947), Süss, (1958 and 1960).

(Rehmatullah, 1971) carried out the first systematic study on the wood fossil specimens from the Late Tertiary deposit of Sindh. He discovered a new species of *Sapindoxylon petaronesis*. Later on, Prof. K.M. Khan and his co-workers carried out several field expeditions in Rehman Dhoro in the Laki Range from the sediments of the Paleocene to Pleistocene age and from Ranikot Fort area from 1967-1974.Khan, K.M. et al (1974) discovered many new species from these sites. Later on, many Palaeobotanists examined the fossil wood specimens and reported new species and compared them with the other species in the world with same age for the reconstruction of Paleoclimatic conditions.

2.1. Review of National Research articles on Wood Fossils

Some anatomical studies related to the wood fossils of Manchar Formation, Thano Bulla Khan and Ranikot areas have been carried out.

“(Shar et al., 2007), discovered a fresh species of fossilized wood, *Shoreoxylon* ranikotensis sp. nov., from the Quaternary deposit of the Dada formation in the Ranikot Fort region of the Jamshoro District, Sindh, Pakistan. He found that this specimen's microscopic features closely resemble those of the genus *Shorea* in the family "*Dipteriocarpiaceae*".

“(Ahmed et al., 2007b), studied the *Euphorioxylon thanobolensis*sp.nov., a new petrified wood specie from Manchar formation Miocene to Pliocene in age exposed near Thana bulla khan, district Jamshoro, Sindh, Pakistan. Additionally, he pointed out that this species' morphological characteristics bear a striking resemblance to those of the *Sapindaceae* family's Euphoria genus. (Ahmed et al., 2007b) also reported that growth rings are absent from this specie which shows that these plants grown in tropical climate. This specie reported first time from this locality”.

“(Ahmed et al., 2007a), made the discovery of a new fossilized wood, *Anogeissoxylon rehmanense sp.nov*., from the Bara formation's Tertiary stratum that was found close to the Rehman Dhoro district in Jamshoro, Sindh, Pakistan. He explained that the current fossil's anatomical traits showed strong resemblances to those of the *Combretaceae* family's genus *Anogeissus*. The plant in issue was growing in a tropical climate, according to contemporary species that are comparable to this taxon."

“(SHABAB ALI KHAN et al., 2016), conducted anatomical on wood fossils collected from Manchar Formation near Thano Bulla Khan, Sindh. On the basis of resemblance its characteristics with genus *Andira*of the family *Fabaceae* and named it *Andiroxylon thanobolensis*sp. nov..The lack of growth rings suggested that the plants were thriving in a tropical climate".

“(Ahmed et al., 2015), worked on rocks and fossils specimens collected fromThano Bulla Khan to provide further detail on the research area's general geology, hydrogeology, fossils, and economic significance of cut stone. The study area's fossils were recognized and given names by the Shabeer Ahmed et al., as COLPHOPHYLLIA, PLESIOLAMPAS and petrified wood".

"(Noor-ul-Ain et al., 1848), collected petrified fossils from Miocene age Manchar Formation uncovered in Thano Bulla Khan, Sindh, Pakistan. She examined all the anatomical features of these wood fossils specimens and discovered new specie belonging to the family *Febaceae*and with genus *Mellitia*. On the basis of comparable features with this genus and location where it is has been discovered, they named it *Mellitioxylon sindhiensis* sp.nov".

"(Soomro et al., 2017), performed Paleoxylotomical (microscopic) research on Miocene petrified wood fossils found in Thana Bulla Khan, Sindh, Pakistan's Manchar Formation. On basis of anatomical characteristics, it is revealed that this specimen has same features like character of Vessels, arrangements of wood Parenchyma and Xylem rays comparable with family *Lytheraceae*. Therefore, it named as *Lagerstroemioxylon thanobolensis* sp. nov.".

(Soomro et al., 2016a), worked on petrified wood fossils collected from the the Miocene Chinji Formation which is visible in the Chinji National Reserve. Standard procedure was used to prepare the three-dimensional slices. They have found the characteristics resemble to the genus*Albizzia* of family leguminosae and named this newly discovered specie as *Albizzioxylonchinjiensis*sp.nov.".

"(Soomro et al., 2016b), conducted studies to examine the evolutionary relationship among angiosperm. In order to examine the anatomical features of petrified wood that was obtained from the Miocene Chinji formation and exposed at the Chinji National Reserve, they conducted systematics on the wood fossils. The microscopic features of the fossil wood were compared to those of fossil woods that are currently known to exist. *Dichrostachy* wood and fossil wood are strikingly similar. It is therefore designated *Dichrostachyoxylon chinjiensis sp*. nov. and is thought to be a new species".

“(Noor-Ul-Ain et al., 2016), gathered wood fossils from the Miocene Chinji Formation, which is exposed at the Chinji National Reserve in the Punjab, Pakistan's Salt Range. (Noor-Ul-Ain et al., 2016) performed anatomical analysis and compared the Taxonomical characteristics with modern wood and fossil wood. Closed examination revealed that features of this wood fossil specimen have close resemblance with family *Fabaceae* and with the wood of *Ormosia*. After analyzing the similarities and differences with previously documented species, *Ormosioxylon chinjiensis sp*. nov. is designated as the new species.”.

“(Arain and Rajput, 2014), collected a single petrified wood specimen from the Miocene Chinji Formation that was exposed at the Chinji National Reservoir. Three-dimensional sections were prepared by(Arain and Rajput, 2014)for anatomical studies. When microscopic traits of specimens were compared to fossil and contemporary wood, it was discovered that they shared a lot of similarities with the *Leguminosae* family. Wood fossil has the closest resemblance with the wood *Ougenia*. Consequently, it is referred to as *Ougenioxylon chienjiensis* sp.nov and is thought to be a new species.

“(Mangi et al., 2020), collected wood fossil specimen from Bara Formation of Sindh, Pakistan. Three dimension sections were prepared from wood fossil specimen. Anatomical features indicate that specie belongs to the family *Burseraceae* of petrified *Bursera* wood and new name given to this specie as *Burseroxylon* on the basis of form genus. The author discovered that the plants were flourishing in a tropical climate and that the specimen had dispersed porosity”.

“(Soomro et al., 2021), examined the wood fossil specimen that was taken from the Manchar Formation and exposed at Thano Bulla Khan, Sindh, Pakistan, using anatomical methods. Three dimensional thin sections were made and author performed anatomical analysis. He compared the features this wood fossil specimen with other wood fossils and modern wood. (Soomro et al., 2021) found that wood fossil specimen has close resemblance with genus *Atalantia Corrêa* of the *Rutaceae* family. As a result, the author determined that the researched features are *Atalantioxylon thanobolensis* sp. nov. with regard to its locality based on a comparison between recent and fossil wood.

"(Parven et al., 2022), conducted anatomical examination on a sample of wood fossils that were taken from the Quaternary Manchar Formation that was exposed at Thano Bulla Khan in Sindh, Pakistan. After studying xylotomical studies, it revealed that this specimen indicated close attributes with genus *Sapota* related to the family *Sapotaceaee*".

2.2. Review of International Research articles on Wood Fossils

"(Choi et al., 2010), 82 petrified wood specimens from a Miocene deposit were gathered from Yamagata Prefecture's western shore in Japan. Twenty-two taxa were identified by the authors, comprising species of 17 dicotyledons and 5 conifers. Along with two species not previously known from Yamagata, Japan's Miocene, the authors also described five new species (*Chamaecyparisparathyoides, Pterocaryaparvipora, Populussoyaensis, Schimaprotowallichii, Lagerstroemia odaniense*).After discovery of new species and identification of wood fossils species by the authors, total number of wood fossils taxa related to Yamagata became 39. Authors found warm temperate species of *Keteleeria*, *Liquidambar, Distylium* and *Lagerstromeia* in the foundation. The authors also discovered that, with the exception of the Onisakatoge Formation, the woody specimens in the other three Miocene age formations gradually transitioned from a mixture of warm and mild elements to a warm temperate assemblage during the Miocene period. They concluded that due to the during the Miocene time in Japan vegetation changed from cool to warm temperate assemblages such as from Aniai type to the Daijima-type".

“(Mehrotra et al., 2011), collected examples of petrified wood from two recently discovered fossilized sites in the Assamese districts of Dhemaji and Lakhimpur. The purpose of their field excursion is to reconstruct Paleoclimate. These fossil sites are Middle-Late Miocene in age. For the reconstruction of the Paleoclimatic, numerous fossil wood fragments from two recently discovered fossil locations in the Assamese districts of Dhemaji and Lakhimpur were gathered and examined. They have validated the similarities with *Gluta* (Anacardiaceae), *Bischofia* (Euphorbiaceae), *Bauhinia, Cynometra, Copaifera-Detarium-Sindora, Millettia-Pongamia, and Afzelia-Intsia* (Fabaceae) and belong to the Tipam Group, which is thought to be Middle–Late Miocene in age.The flora also discovered as a new specie of *Bauhinia* and named *Bauhinia miocenia* sp. nov. The scientists conclude that the existence of this flora in this area throughout the Miocene era suggests a warm, humid climate during the formations' deposition. In the Miocene, there was a floral element interchange between India and Southeast Asia, as evidenced by the discovery of wood remains from that region."

“(Denk et al., 2019), evaluated the Miocene flora and climate by looking at the leaf record, Palynological assemblages, and wood fossils from 36 locations in western and central Turkey. Based on radiometric dating and the ages of the animal and fauna, the authors verified the age of the flora. Leaf flora belongs to the Güvem (Beş Konak, Keseköy), Turkey. To reconstruct the Paleoclimatic of the modern forest of the area, the authors utilized Köppen signatures using the Climate Leaf-Analysis Multivariate Program (CLAMP). Examinations revealed that most of the pollen flora controlled by pollen flora which is 85 to 98% in range and indicated the existence wide spread forests in that time. With the help of pollen diagrams, authors illustrated the shift of swamp forest to well-drained forests (Pinaceae) which shows the variations lake level or basin development. The researchers speculate that the spread of xeric forest vegetation may be linked to this shift and that false tree rings may provide seasonal climate information. Diagrams of pollen illustrate the existence of zonal, azonal broadleaf and needle leaf and extra zonal open vegetation forests. Scientists compared the ancient flora with younger flora and found that despite the rise in global temperature during Mid-Miocene Climate Optimum, this prehistoric flora shows no increase in diversity or adoption of climate.”

“(Gentis et al., 2022), gathered thirty specimens of petrified wood fossils from the upper and lowermost middle Miocene Natma Formation in Central Myanmar, Burma, and annotated twenty taxa. The purpose of author research is to understand the evolution of Asian monsoonal ecosystem through time. Author s found that fossil specimens show close similarities with present *Fabaceae, Dipterocarpaceae, Burseraceae, Moraceae and Cupressaceae*. They also include abundant diversity of fossil Diptocarps (eight species) which are found in todays’ South Asian rainforests. In addition to providing information about the prehistoric forest's various seasons with coastal, mixed-to-dry deciduous, and wet evergreen species, living tree species have demonstrated relationships with these fossil assemblages. According to the authors' reconstruction, Myanmar experienced a warm, humid monsoonal climate in the late prehistoric era.”

“(Stepanova et al., 2022), collected well-preserved mummified wood fossils of *Juniperus sp*. from the deeper strata of the Taman Peninsula, South Russia's Popov Kamen area to clarify the taxonomic position and provide insight into the phytogeographic past of the extant *Juniperus L*. species.Well preserved fossil allowed researchers to apply all method which are used to study the anatomical features of modern wood. This fossil wood specimen showed similarity to the *J.excelsa*. Mediterranean species belong to the section Sabina. J. excelsa is only reliable macrofossils from Sabina section from Eurasia dated to Miocene age. Authors discovered that wood fossil specimen of *Juniperus sp*. was not buried in situ, because it was buried in deep water sediments. The macrofossils and pollen series from Cupressaceae, found in its surroundings region, proposed that *Juniperus sp.* wood was likely shifted by sea current from the northwestern side of the Black Sea, which was a part of the Eastern Para Tethys”.

“(Martínez et al., 2023), gathered 121 specimens of wood fossils in all from Barro Colorado Island, Panama. The age of around ~22.79 Ma is obtained from radiometric dating of tuff associated with wood remains, designating an Early Miocene epoch. Authors conducted anatomical studies on wood fossils specimens and found that these specimens belong similar in morphotype and physical characteristics resembling those of the native South Asian mangrove tree *Sonneratia* (Lythraceae). Authors named this newly discovered specie as: *Sonneratioxylon barrocoloradoensis Pérez-Lara., sp*. nov.Authors also conducted Biomechanical studies which discovered that *S. barrocoloradoensis* tree has a mean height of 25m which reached in some specimens up to 40m, in contrast to the modern specie Sonneratia which have lower mean heights. Because S. *barrocoloradoensis* is dominant and shares similarities with *Sonneratia*, it was assumed that the fossil wood assemblage on Barro Colorado Island was made up of a mangrove forest that was growing along the coast of the central Panamanian volcanic arc. According to the experts, marginal marine to coastal fluvial environments were ideal for the fossil trees to thrive and were submerged in a volcanic lahar flow in a single incident, according to their stratigraphic and sedimentological study".

2.3. Review of International Research articles on $\delta^{13}C$

"(Buurman, 1972), To ascertain the many facets of the mineralization of fossil wood, Buurman studied specimens that were acquired from several museums and private collections. According to his research article, the study's objective was to compare a variety of wood mineralization to determine whether Permineralization or the replacement of wood structures had taken place. Additionally, a comparison between the chalcedonic and "wood-opal" mineralization structures appeared significant".

"(Benner et al., 1987), Banner carried out the study "Depletion of $\delta^{13}C$ in lignin and its application for stable Carbon Isotope studies. Many different types of vesicular plants, such as *Spartina alteriflora*, the salt-marsh grass, had their carbon isotope compositions of polysaccharide and lignin components found to differ significantly. They also showed that during biochemical processing, as polysaccharides are preferentially removed from *Spartina detritus,* the carbon isotope composition of the material alters, resulting in a substance that is substantially richer in carbon originating from lignin and depleted in ^{13}C. ".

“(Martinelli et al., 1998), explored a tropical forest in Rondonia, Brazil, and measured the stable carbon isotope ratio of tree leaves, boles, and fine litter. The wood from 36 tree boles, 208 tree leaves that were gathered for isotopic analysis and 18 samples of fine litter from a terra-fire forest in Samuel Ecological Reserve, Rondonia State, in the southwest Amazon region were all included in the study. The values of $\delta^{13}C$ in leaves ranged from -28‰ to -36‰, with an average (+ 1SD) of -32.1‰ + 1.5‰, which was lower than the values of $\delta^{13}C$ in fine litter (-28.7‰ + 2.0‰) and bole samples (-28.4‰ + 2.0‰)”.

“(van Bergen and Poole, 2002), completed thorough stable carbon isotope and molecular analyses on the set of two archaeological and ten wood fossil specimens in order to shed light on their potential application as rigorous, independent paleoclimatic and paleoenvironmental criteria. Extensive analyses of stable carbon isotopes and molecules in wood specimens from fossils and archaeology have shown significant variations in their isotopic composition. While part of this variance may have come from natural heterogeneity, the majority of isotope discrepancies between the Tertiary and archeological specimens can be explained by the degree of lignin change or the amount of polysaccharides present. Based on the molecular data, the Cretaceous specimens only significantly modified lignin, almost little intact 2-methoxyphenol lignin building blocks preservation, and no evidence of polysaccharides. One of the primary reasons for the unique $\delta^{13}C$ enriched readings of these specimens is the hypothesized drastic change in chemical makeup. Overall, these data make it abundantly evident how crucial it is to combine stable carbon isotope data using comprehensive molecular data on the different constituents of wood to enhance our comprehension of the potential applications of stable carbon isotopes from wood for paleoclimatic and paleoenvironmental interpretations”.

“(Sass et al., 2004), investigated three sub-fossil oak stem discs (Z25, Z74, and Z162) that had heartwood that had been preserved and had been gathered while an ancient forest was being excavated at Zwolle-Stadshagen, in the eastern Netherlands. Their goal is to investigate the relative variations in stable carbon ($\delta^{13}C$) and oxygen

($\delta^{18}O$) isotope composition in three bog oaks from Zwolle, eastern Netherlands, during inhibited and normal development periods that are dated between approximately 200 BC and 150 AD. They came to the conclusion that although the stable carbon and oxygen isotope ratios of wood and cellulose did not retain environmental changes, ring-width chronologies of bog oaks serve as a sensitive environmental monitor".

"(Robinson and Hesselbo, 2004), identified the fossil-wood carbon isotope stratigraphy found in the Wessex Formation, a non-marine unit in the Wealden Group of the Isle of Wight and Dorset, Southern England, which belongs to the Lower Cretaceous (Valanginian–Barremian) period. The range of the carbon-isotope levels (^{13}C c.26.6 to 19.8‰), according to the author, is in line with what is predicted for Mesozoic C_3 plants. By considering the fossil-wood carbon-isotope data from Dorset and the Isle of Wight, a composite fossil-wood carbon-isotope curve for almost the whole Wealden Group may be created. Stage-level chrono-stratigraphy for the Wealden Group can be applied tentatively because of a possible correlation with a Tethyan reference carbon-isotope curve. Correlations indicate that the Valanginian is either condensed or partially absent from the Wealden Group deposits, which are primarily of Hauterivian and Barremian age. The reported carbon-isotope data show that atmosphere CO_2 accurately tracks the marine reservoir's carbon isotopic makeup, even during times of relative carbon-cycle quiescence".

"(Bechtel et al., 2008), For organic petrological and geochemical study, Bethal used samples from coals, coaly shale, and well-defined stratigraphic units to determine the amount of $\delta^{13}C$ alterations caused by Tertiary environmental changes. The average carbon isotope values of coal with low hopanoid concentrations and low liptinite macroalgal contents are compared. The $\delta^{13}C$ values of the associated gymnosperm-dominated flora are reconstructed based on the composition of terpenoid biomarkers and their association with the carbon isotopic composition of the coal seams. The $\delta^{13}C$ measurements of the coal deposits are further adjusted because fluctuations in the $\delta^{13}C$ of atmospheric CO_2 during the Tertiary were reconstructed from the $\delta^{13}C$ values of benthic foraminifera. Due to their impact on plant physiology, they discovered that the primary cause of the observed patterns was variations in the atmospheric and oceanic carbon stocks' isotope ratios. Climate change also had an extra moderating effect. The shifting $\delta^{13}C$ values of atmospheric CO_2 linked to atmospheric pCO_2 and paleoclimate are indicated by the terrestrial carbon isotope record. An effective method for reconstructing the isotopic record of land plants and its Carbon isotope study on lignite, ancient wood of known taxa, and cellulose has implications for environmental changes throughout Earth's history".

"(Mehrotra et al., 2011), studied fossil wood from the Middle to Late Miocene from the Assamese districts of Dhemaji and Lakhimpur, India, to create a paleo-environment and paleoclimate. They belong to the Tipam Group and are of seven types, namely *Glutoxylonburmense*, *Bischofiapalaeojavanica*, *Bauhinia miocenica*, *Cynometroxylon holdenii*, *Hopeoxylon assamicum*, *Millettioxylon pongamiensis* and *Pahudioxylon deomaliense* of which *B. miocenica* is a new species. It is clear from the distribution pattern of their modern counterparts that a tropical climate prevailed in the region throughout the depositional period. Upper Assam most likely had a warm, humid climate in the middle to late Miocene because most of the taxa are found in tropical evergreen to damp deciduous, littoral, and swampy forests. The presence of some Southeast Asian elements in the fossil assemblage amply illustrates the complete suturing between the Indian and Asian plates, which permitted taxonomic migration".

"(Ajaykumar11 et al.), worked on the carbonized wood fossils buried in the sand of the Meenachil River Basin in India to highlight the significance of these fossils, their many forms of preservation, the role they play in reconstructing the paleoclimatology and paleoenvironment of a place, and the challenges associated with recognizing them".

"(Kłusek and Pawełczyk, 2014), conducted research on samples of Sub-fossil wood, collected from Austrian Alps to analyze the stable Carbon isotopes. These samples were representing six various periods. $\delta^{13}C$ value for each period calculated carefully. They examined the consequences of measuring sub-fossil wood from

Schwarzersee Lake using stable carbon isotopes. The development of an appropriate wood preparation method, according to the authors, is essential for both practical and high-quality reasons, as the planned research can be completed much more quickly and at a significantly lower cost thanks to the suggested removal of the resin extraction procedure”.

“(Gessler et al., 2014), examined and found that the stable isotopes within tree rings are moving toward a mechanistic comprehension of isotope splitting and mixing processes from the leaves to the wood in order to comprehend leaf-level processes like the isotopic composition of inorganic sources (CO_2 and H_2O) and photosynthetic carbon isotope separation. Researchers focused on the "downstream" metabolic and transport systems, which have received less attention. Additionally, they give a summary of the roles played by cellulose and lignin, two important wood-forming chemicals, as well as the processes controlling the transfer of photosynthate (sucrose) and associated isotopic signals. They talked about the general topics of post-carboxylation carbon isotope separation and organic oxygen exchange with water within the tree”.

“(Bardet and Pournou, 2015), used optical and electron microscopy to examine the morphology of two distinct wood fossils and ^{13}C CPMAS NMR to analyze the preservation of the fossil wood. The first one, which concerns the No. 10 trunk of the Bükkábrány Miocene woods in Hungary, was provided by the Hermann Ottó Museum. The second sample is a petrified trunk from the Oligocene epoch that was found in Switzerland and is from the Bureau of Culture of the Republic and Canton Jura. The results of the analysis performed by the author on the two specimens demonstrated that neither petrification nor coalification is responsible for the exceptional state of preservation of the Miocene fossil. A plausible explanation for Bükkábrány trunks' condition is mummification; however, as this fossilization process is poorly understood, further research must be done on this theory”.

"(Lukens et al., 2019), evaluated the effects of digenesis on samples of prehistoric wood's carbon isotope values collected from lacustrine and deltaic deposits in the following locations: the Eureka Sound Formation on Banks Island, Northwest Territories, Canada; the Yongning Formation in Nanning, China; the Khapchansky locality in Northeast Siberia; and the Xiaolongtan Formation in Yunnan Province, China. Modern and fossil wood's carbon isotope ($\delta^{13}C$) value is frequently utilized as a stand-in for changes in the climate and environment. Before climatic signals are interpreted, tissues from tree-rings tissue $\delta^{13}C$ readings are usually corrected for variations in the $\delta^{13}C$ value of atmospheric CO_2 and pCO_2 (McCarroll et al., 2009; Treydte et al., 2009; Wang et al., 2011; Schubert and Timmermann, 2015; Trahan and Schubert, 2016). Laboratory measurements and a collection of the literature show that the apparent enrichment between $\delta^{13}C$cell and $\delta^{13}C$ wood is consistent across a wide range of environments, temperatures, and taxonomic groups. Researchers working in these fields shouldn't have to spend time and resources on labor-intensive cellulose extraction processes because there is a 1:1 link between $\delta^{13}C$ cell and $\delta^{13}C$wood in both modern and Holocene trees. Additionally, the association between $\delta^{13}C$ cell and $\delta^{13}C$wood in deep-time samples indicates that every substrate offers comparable paleo-environmental data; however, it can only detect relative differences in the $\delta^{13}C$ value. When comparing the $\delta^{13}C$ wood values of fossil and current trees, workers should modify the results based on the cellulose content, as seen by the higher ε values discovered in deep-time samples".

"(Friedman et al., 2019), performed investigation on how aging and climatic variations contribute differently to the *Populus* genus, which is dominant in North American, European, and Asian floodplain forests. The aim of this study is to examine the possibility of using $\delta^{13}C$ in cottonwood tree rings to reconstruct climate and river flow. In their investigation, they focused on the following primary issues:

1. Does the age of a tree affect the $\delta^{13}C$ of cellulose and entire wood?
2. What changes in cellulose, hemicellulose, and lignin concentrations occur with the age of the tree?

3. What relationships exist between flow, precipitation, and the annual series of $\delta^{13}C$, and how do these relationships differ from those for ring width?

They took samples of trees ranging in age from two hundred years to two hundred years to differentiate between the impacts of annual climate change and tree age. Following the $\delta^{13}C$ isotope study on 336 randomly chosen plains cottonwood, they discovered that $\delta^{13}C$ in cellulose extracted from *Populus* tree rings can be used to recreate multi-century records of historical drought. They found a substantial correlation between the $\delta^{13}C$ of yearly rings and precipitation and a modest correlation with river flow. However, age also had an impact on $\delta^{13}C$ of whole wood. Furthermore, it is discovered that $\delta^{13}C$ in cellulose extracted from Populus tree rings can be used to reconstruct multi-century records of historical dryness. They found a substantial correlation between the $\delta^{13}C$ of yearly rings and precipitation and a modest correlation with river flow. However, age also had an impact on $\delta^{13}C$ of whole wood. The author discovered a hitherto unknown juvenile effect in Populus, characterized by a decreased $\delta^{13}C$ during the first thirty years of the tree's existence. After that, as the percentage of cellulose reduced, $\delta^{13}C$ fell as the number of years from the pith increased".

"(Hercman et al., 2019), performed a series of laboratory experiments to ratio of stable isotopes of$\delta^{13}C$ composition in various products formed due to the burning/ pyrolysis of wood and oak fossil wood. They observed variation of $\delta^{13}C$ up to 4‰. The differences in between compositions of isotopes of Carbon's products were dependent up on temperature, time and wood type. Author compared the results of fresh and fossil oak wood and revealed that the $\delta^{13}C$ differences were affected due to the decomposition of some wood constituents at the time of process of fossilization. Author also suggested that the variation of $\delta^{13}C$ ratio on temperature could be due to the exchange of isotopes in between different products".

"(Nordt et al., 2016), compiled a values of 6888 $\delta^{13}Cp$ (where $\delta^{13}Cp$ is Carbon Isotopic signature of product) ten Carbon sources' worth of data from published works fall between average -24.6 $\pm$ 1.7‰ (ISOORG data base). Before (Nordt et al., 2016), many authors conducted numerous studies on the collection of data of ($\delta^{13}C$) from marine sediments, and atmosphere to comprehend how carbon is transferred worldwide across the oceans, land, and atmosphere. Few of them have worked for extended periods of time on terrestrial plants. In this paper (Nordt et al., 2016), applied following three methods to analyze the trends in stable carbon isotopes from C_3 plants ($\delta^{13}Cp$) during the last 450 Ma years in time steps of 5 Ma.;

i. A set of 6888 $\delta^{13}Cp$ numbers (average − 24.6 ± 1.7‰) from the literature's ten carbon sources (ISOORG database).
ii. According to second method, the main factors influencing the $\delta^{13}Cp$ are the ambient CO_2's $\delta^{13}C$ ($\delta^{13}Ca$) and the isotopic fractionation that results from photosynthesis's carboxylation and diffusion (MOD_1)
iii. The third method postulates that when atmospheric CO_2 content (pCO_2) exceeds mean Holocene conditions (MOD_2), physiological-driven isotope fractionation occurs during photosynthesis.

Author compared the values and results of ISOORG and MOD1, MOD2 and found that during the time when pCO_2 was high and level of $\delta^{13}Cp$ is lower by up to 6‰. However local and regional climate variables may have an impact, the author discovered averaged the $\delta^{13}Cp$ of multiple plant sources in many of the 5 million year age bins using ten Positive Carbon Isotopic Excursions (PCIEs) in ISOORG. The majority of the trips occurred during cool to glacial temps or ocean anoxic events, according to the author".

2.4. Current References on $\delta^{13}C$

"(Singh and Ghosh, 2023), conducted research on ^{13}C variations during the period of 1832 to 1880 with the help of sample papers to reconstruct the climatic record. Sample papers serve as an important record for reconstructing the Anthropocene era, according to the authors, because of the printing industry's rapid rise throughout that period. Additionally, they observed an upward trend in ^{13}C values from 1832 to 1880. Sample papers are a more economical approach that doesn't require a lot of fieldwork to gather samples from tree rings. That's why it is considered as substitute for tree rings for the reconstruction of Paleoclimatic condition during Anthropocene time. Stable isotopic studies are extensively used in the reconstruction of Paleo climatic are widely used in climatology, isotopic ranges in tree rings, ice cores, and marine sediments, which allow researchers to decipher historical climatic conditions on a global scale".

"(Rugmai and Grote, 2023), conducted research on late Middle Pleistocene sediment samples collected from a prominent fossil site in Northeastern Thailand and processed for pollen analysis and plant community reconstruction. The sediment layer was collected from ancient river tributary from late Middle Pleistocene in age. Authors' research discovered that plants belong to different habitats: riparian, evergreen and deciduous forests, and also a high proportion of grasses. The indication therefore recommends that the ecosystems of the area contained of gallery forest and open woodland, where the gallery forest persevered along the ancient river and the landscape farther from the river appeared to be open woodland in which Quercus dominated".

"(Salomón et al., 2023), The carbon isotopic signature of CO_2 breathed in darkly by leaves ($\delta^{13}Cr$) in the woody stems and green shoots of cedar, oak, and maple (*Acer platanoides* L., *Quercus robur* L.). (*Thujaoccidentalis L.*). Salomon measured trees in the spring and late summer using the Cavity Ring-Down Laser Spectroscopy technique. Understanding the distribution of carbon in plants can be aided by being aware of the isotopic breakdown and substrate of the respiratory process, as indicated by the carbon isotope makeup of CO_2 in breath ($\delta^{13}Cb$) in bulk organic matter and the amount of respired CO_2 ($\delta^{13}Cr$) in many plant parts. The authors assessed potential drivers of respiratory fractions in growth, respiration, photosynthesis, and non-structural carbohydrate activities. After careful analysis, the scientists discovered that maple and oak branches were enriched in ^{13}C relative to $\delta^{13}CB$ in the spring because of respiration, but not in the stem or in late summer. It was observed by the author that in Cedar, with respiration of CO_2, amount of $\delta^{13}CR$ is not prominent in organs and seasons while ^{13}C-deplated relative to $\delta^{13}CB$.Authors described the relations of between $\delta^{13}CR$ and respiratory pathways".

"(Leland et al., 2023), examined the environmental factors regulating the parameters of $\delta^{13}C$ and $\delta^{18}O$ by evaluating a Siberian pine tree ring record spanning 182 years (Pinussibirica Du Tour) from Khorgo Lava, a xeric location in central Mongolia. The authors first observed that tree-ring $\delta^{13}C$ and $\delta^{18}O$ were sensitive to climate and compared it with the ring-width record, which throughout the past 2,000 years has had a significant impact on Central Magnolia's hydro-climate. Isotopic records of long-lived conifers (strip-bark morphology) growing in resource-limited environments were compared with those of trees with full cambium (whole-bark morphology) in order to assess the secondary leaf-level physiological activity of these trees. The scientists concluded that recent conditions, situations of extreme drought, and summer hydro-climatic conditions were reflective of fluctuations in tree-ring $\delta^{13}C$ and $\delta^{18}O$. Tree-ring $\delta^{13}C$ and $\delta^{18}O$ are indicators of the climate".

2.5. References of National Research articles on $\delta^{13}C$

"(Morgan et al., 2009), conducted Isotopic research on mammalian tooth enamel, collected Potwar region to reconstruct the ecological gradient of vegetation in sub-Himalayan alluvial plains of late Miocene in age. On the basis of ^{13}C, authors found depletion ^{13}C from northeast fossil localities to southwestern localities. In *equids*, *giraffids*, *suids*, *sivapithecine hominoids*, and *anthracotheres*, they discovered this tendency of ^{13}C depletion".

"(Waseem et al., 2021), this study is a component of Dr. Tahir Waseem's doctoral thesis, which the Higher Education Commission (HEC) of Pakistan funded. Dr. Tahir and his co-authors, compiled datasets of Carbon Isotopes to evaluate the expansion of C4 grassland with help of fossil tooth enamel and Paleosol. They have compiled approximately data of 458 fossil tooth enamels. They used data of $\delta^{13}C$ and $\delta^{18}O$ to evaluate the prehistoric climate. Ancient climates remnants found on fossil teeth's enamel allow scientists to learn how climatic shifts over time impacted changes in flora and fauna. It is stated that the Siwalik sub-Group of Pakistan experienced the growth of C_4 grasslands circa 8–7 Ma, but it is unknown whence C_3 began to change into C_4 in the Siwalik floodplains. Enamel on the tooth of herbivores indicated that C_3 vegetation not entirely disappeared at the end late Miocene due to the expansion of C_4 vegetation because C_3 vegetation was preserved in pockets of flood plains. At the end of Miocene period animals consumed C_3 diet. Researchers all over the world further modulate the expansion of C_4 vegetation at the end of Miocene. The same situation was seen in low-latitude North America, South America, and East Africa, where C_4 grasslands spread swiftly as a result of a drop in the partial pressure of carbon dioxide (pCO_2). Authors also assumed that during *ca*17 Ma, C_4 did not increase in high –latitude of North America and area close to the arctic regions. Researchers draw the conclusion that this data indicates that the single main worldwide driver, a decline in pCO_2, caused C_4 plants to extend at low latitude throughout the late Miocene".

"(Ali et al., 2023), studied the stratigraphic sections of Lower Jurassic in the Indus Basin of Pakistan to characterize the siliciclastic and carbonate strata in the sections. Authors collected samples from the sections for $\delta^{13}C$ and $\delta^{18}O$ and palynology. On the basis of Palynomorphsgraphs, authors identified a single Hettigian-Pliensbachian assemblage biozone (HPABZ) in the Lower Jurassic succession. They found the negative shift in $\delta^{13}C$ and $\delta^{18}O$ with Oceanic anoxic event 2-3‰ across the early Jurassic period".

"(Ullah et al., 2023),conducted an integrated studies with help of isotopes and sedimentological analysis to illustrate the depositional environmental model, digenesis, and Southeast Pakistan's Hazara region is home to the Lower Eocene Margala Hill Limestone, which is classified as a reservoir in five stratigraphic layers. Based on petrographic studies, the authors determined the depositional conditions of the Margala

Hill limestone in southeast Hazara, Pakistan. Additionally, they determined the formation's six microfacies (wacke-to-packstone). Margala Hill Limestone exhibits a variety of cementing materials, including ferroan and non-Ferroan cement (granular, blocky, drusy, and microcrystalline). Authors performed ($\delta^{13}C$ and $\delta^{18}O$) analysis and found that marine, meteoritic and burial digenesis affected the Margala Hill Limestone”.

CHAPTER 03

RESEARCH METHODOLOGY

Field work conducted in the area of Rani Kot Fort for the collection of "Petrified Wood Fossils" from the Manchar Formation in 2021 by the author along with Mr. Khalid Ahmed Mirani, Associate Curator, Earth Sciences Division of Pakistan Museum of Natural History (PMNH), Garden Avenue, Shakarparian, Islamabad for the collection of Wood Fossils for various purposes of research and display at PMNH. In order to achieve these goals, following methodology taken into consideration for this research work:

i. Samples collected from the Manchar formation, Rani Kot locality and location marked on map.
ii. Samples sent to the Pakistan Institute of Nuclear Science and Technology (PINSTECH) for (Solid-state Cross-Polarization Magic Angle Spinning Carbon-13 Nuclear Magnetic Resonance CPMAS ^{13}C NMR analysis.
iii. Three dimensional sections (transverse, tangential and radial) prepared by ground thin section technique and studied under the electronic microscope to identify its morphology.
iv. The selected specimen photographed which will act as original description of species.

v. The rectification also is done with the help of inside wood project launch on internet by International Association of Wood Anatomy (IAWA).

3.1. Selection of samples

Fresh, non-weathered, fragmented piceses of petrified wood fossils slected from field collection for further analysis. The location of samples is shown in Table 3.1.andmarked on the satellite map of the study area in Fig. 3.1.:

Table 3:1 Location of Wood Fossils Specimens

Sr. No.	Specimen given name	Longitude	Latitude
1.	61/Man/RK/11	67.92752	25.87632
2.	77/Man/RK/11	67.92906	25.86911
3.	78/Man/RK/11	67.92681	25.87207
4.	84/Man/RK/11	67.92244	25.8645
5.	89/Man/RK/11	67.92894	25.86746
6.	95/Man/RK/11	67.92894	25.8651
7.	108/Man/RK/11	67.93201	25.86392

3.2. Physical Examination of Samples

The collected wood fossils specimens during the field excursion 2011 properly catalogued numbered and preserved in the repository of Earth Sciences Division of

PMNH. The collected specimens designated as 61/Man/RK/11, 77/Man/RK/11, 78/Man/RK/11, 84/Man/RK/11, 89/Man/RK/11, 95/Man/RK/11 and 108/Man/RK/11. In the above mentioned sequences, number indicating the number of specimen, “Man” stands for Manchar Formation, “RK” stands for Rani Kot area and “11” is stands for the year 2011. The length and width of specimens measured in centimeters and marked the length of specimen which is to be cut for ^{13}C isotopic studies. Each specimen photographed, properly and acts as an original description (Fig. 3.1, Fig. 3.2, Fig. 3.3, Fig. 3.4, Fig. 3.5, Fig. 3.6 and Fig. 3.7).

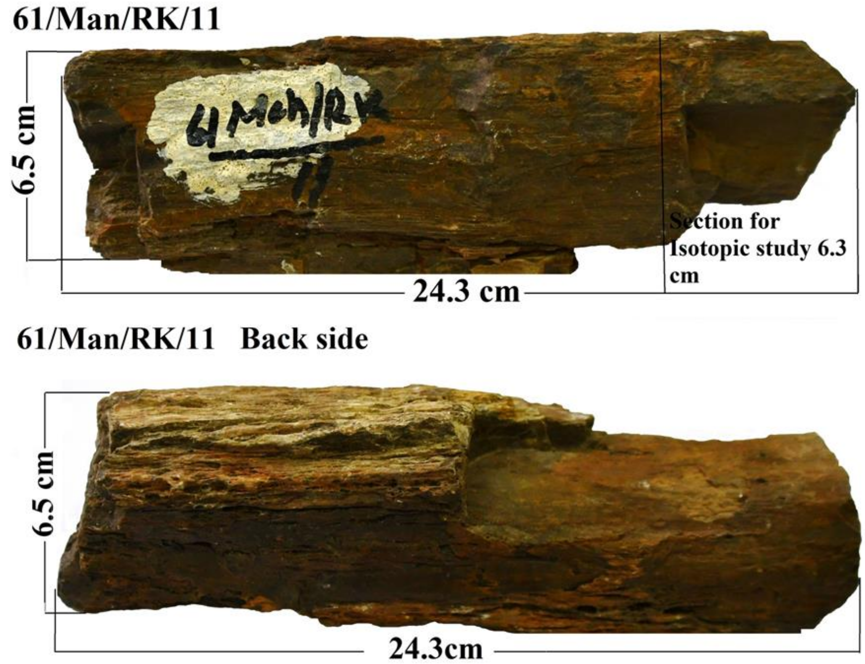


Figure 3.1 Measurement of petrified wood fossil No. 61/Man/RK/11

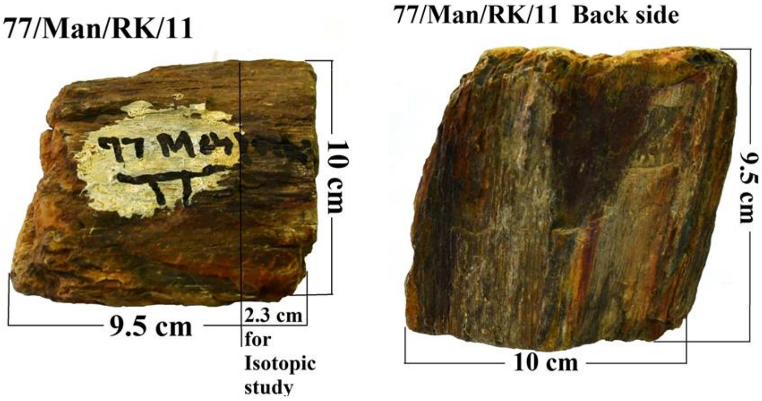


Figure 3.2 Measurement of petrified wood fossil No. 77/Man/RK/11

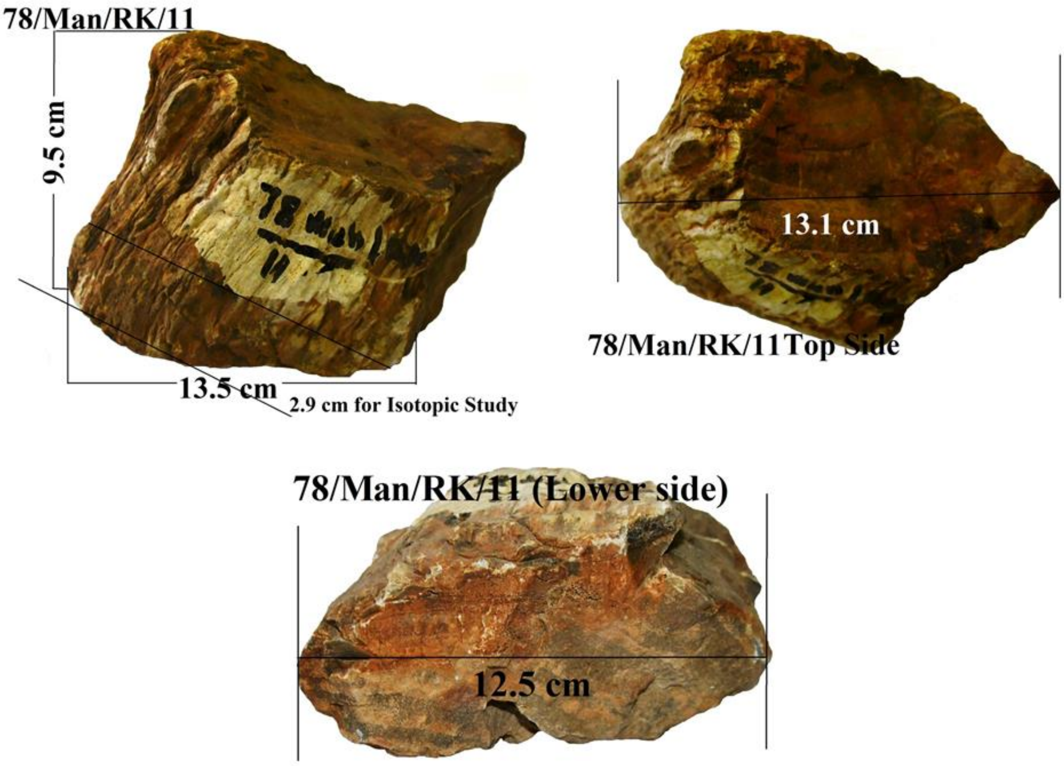


Figure 3.3 Measurement of Petrified Wood Fossil No78/Man/RK/11

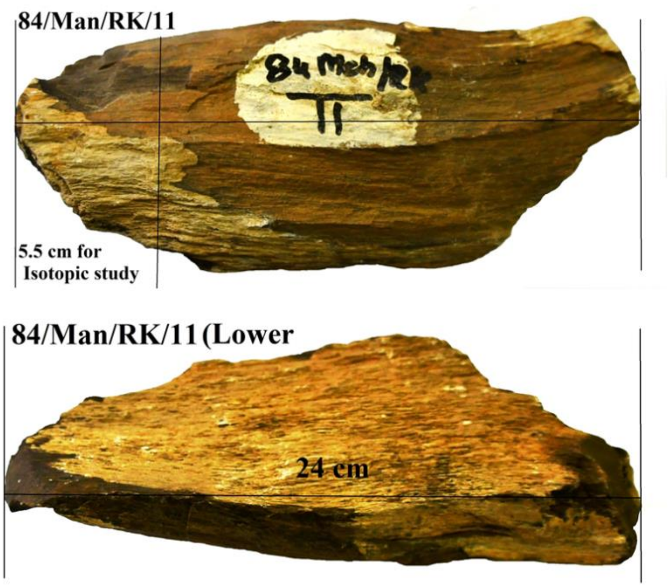


Figure 3.4 Measurement of petrified wood fossil No. 84/Man/RK/11

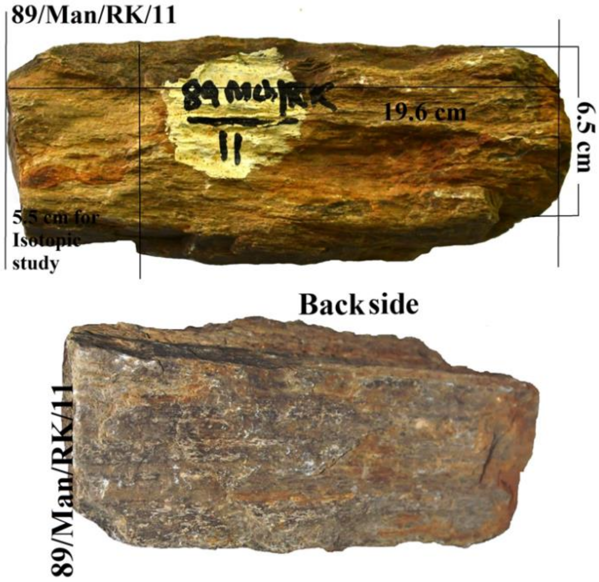


Figure 3.5 Measurement of petrified wood fossil No. 89/Man/RK/11

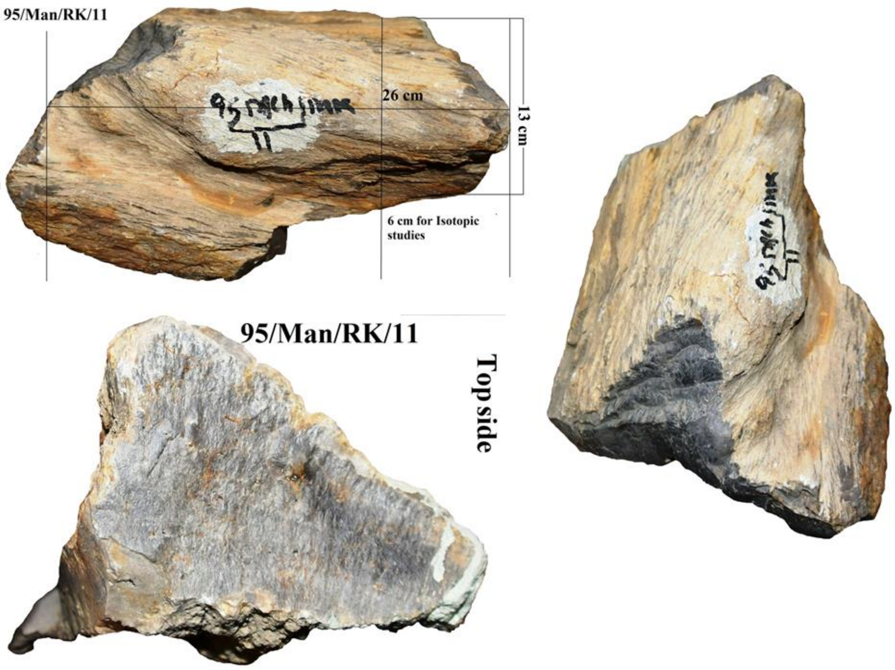


Figure 3.6 Measurement of Petrified Wood Fossil No. 95/Man/RK/11

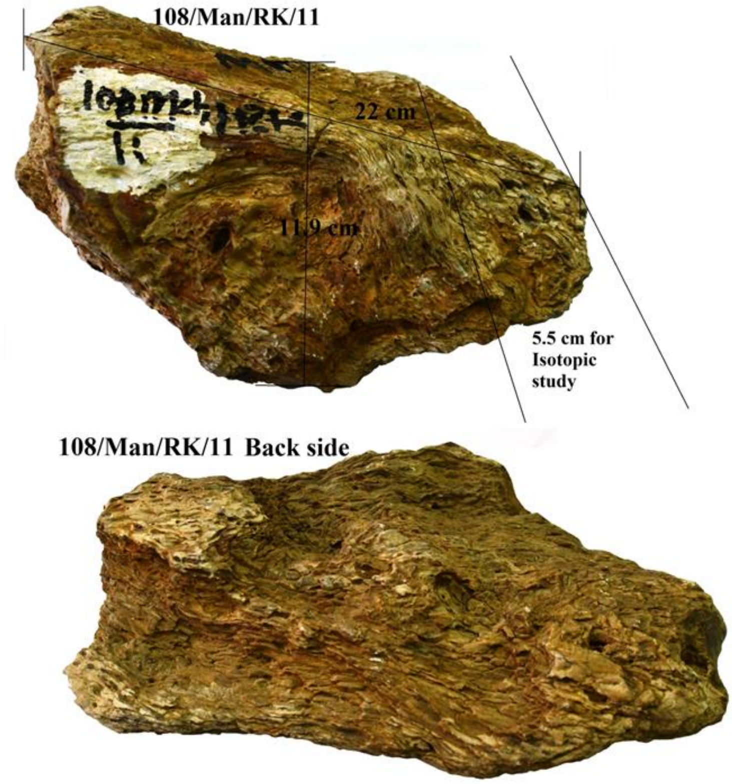


Figure 3.7 Measurement of petrified wood fossil No. 108/Man/RK/11

3.3. Sample preparation

Selected wood fossils specimens washed, clean and processed at PMNH. Wood fossils specimens marked for cutting and brought to the thin section repository where they cut into the required pieces for making slabs for thin sections and for pulverization for ^{13}C analysis (Fig. 3.8). Wood fossils specimens cut on the Rock cutter at PMNH for making required pieces for thin sections and Pulverization for ^{13}C analysis (Fig. 3.9).

Figure 3.8 Petrified wood fossil specimens marked for cutting for making slabs for thin sections

Figure 3.9 Wood fossil specimen cut along the marked surface for further processing

3.4. METHOD

Fossilized Wood samples were cut into three dimensional sections i.e. Transverse, Tangential and Radial (Fig. 3.10. and Fig. 3.11.) on Rock cutter having diamond impregnated cutting disc at PMNH for making thin sections for xylotomical studies (Fig. 3.12., Fig. 3.13., Fig. 3.14., and Fig. 3.15.). One specified portion of Wood Fossil specimen cut for “Pulverization”. Pulverization is a process in which hard substance crushed or grind until it turn into powder form for some analysis.

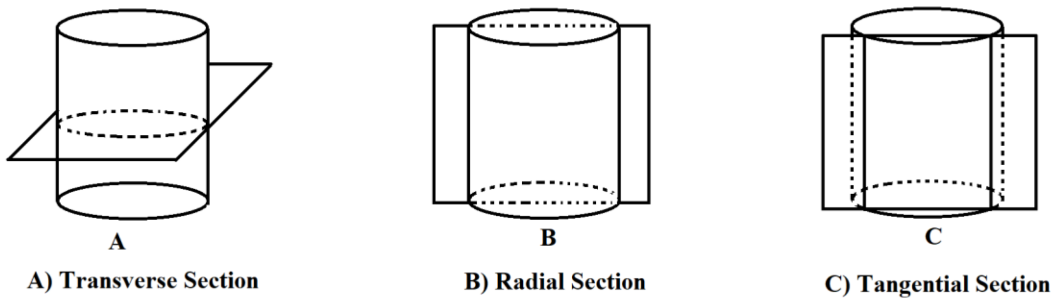


Figure 3.10 Diagram showing the dimension of Wood Fossils cutt

Figure 3.11 Cutting of wood fossils in three dimensions

Figure 3.12 Wood Fossil specimen after cutting into the three dimensions A) Transverse B) Radial and C) Tangential Sections

Figure 3.13 Wood Fossil specimen after cutting into the three Dimensions A) Transverse B) Radial and C) Tangential Sections

Figure 3.14 Cutting of each wood fossil specimen into three dimensions and specified section for 13C analysis (pulverization)

Figure 3.15 Cutting of each Wood Fossil specimen into three dimensions and specified section for 13C analysis (Pulverization)

3.4.1. PREPARATION OF THIN SECTIONS AND ^{13}C ANALYSIS

07 Petrified wood fossils cut into Three-dimensional sections i.e. Transverse, Tangential and Radial (Fig. 3.10. and Fig. 3.15.) at rock cutter facility available at Pakistan Museum of Natural History (PMNH), Islamabad. 21 slabs of specimens of wood fossil specimens were sent to the Hydro Carbon Development Institute of Pakistan (HDIP) Islamabad for making Thin Sections. 07 Wood Fossils sections cut for "Pulverization" were sent to the Geological Survey of Pakistan's Geosciences Advanced Research Laboratories (GSP GARL), Islamabad. 21 Three-dimensional Thin Sections of 07 Wood Fossils received from HDIP, Islamabad (Fig. 3.16., Fig. 3.17., Fig.

3.18., Fig. 3.19., Fig. 3.20., Fig. 3.21., and Fig. 3.22.). For ^{13}C analysis, pulverized specimens of 07 wood fossils sent to the Pakistan Institute of Nuclear Science and Technology (PINTECH), Islamabad.

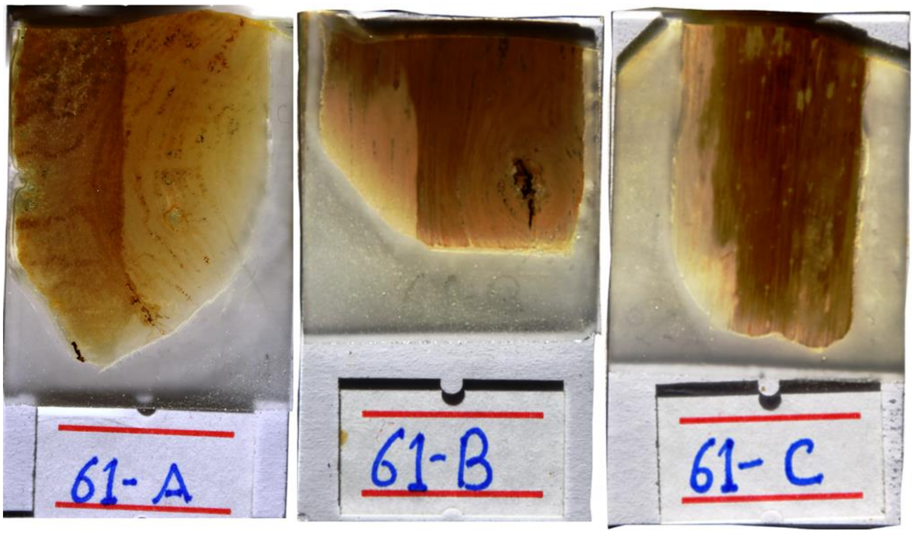


Figure 3.16 Three-dimensional thin sections i.e.(A) Transverse, (B) Radial and (C) Tangential of Wood Fossil No. 61/Man/RK/11

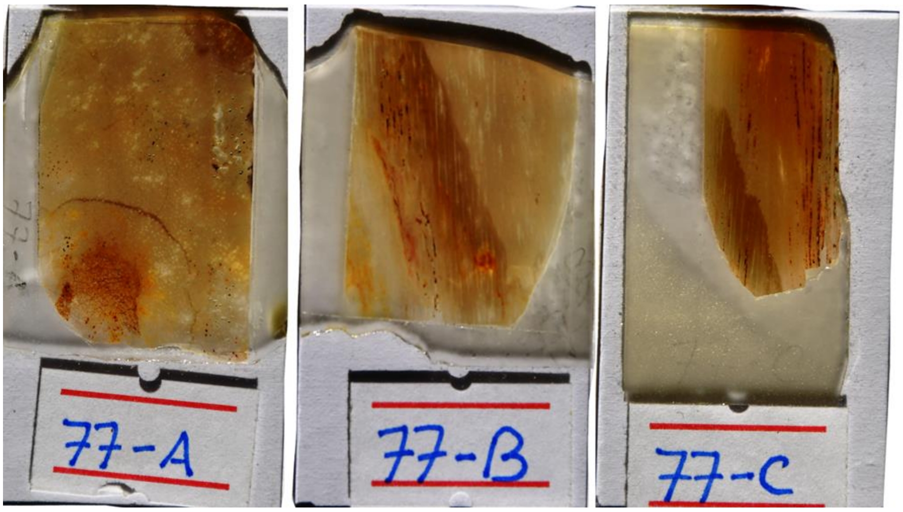


Figure 3.17 Three-dimensional thin sections i.e.(A) Transverse, (B) Radial and (C) Tangential of wood fossil No. 77/Man/RK/11

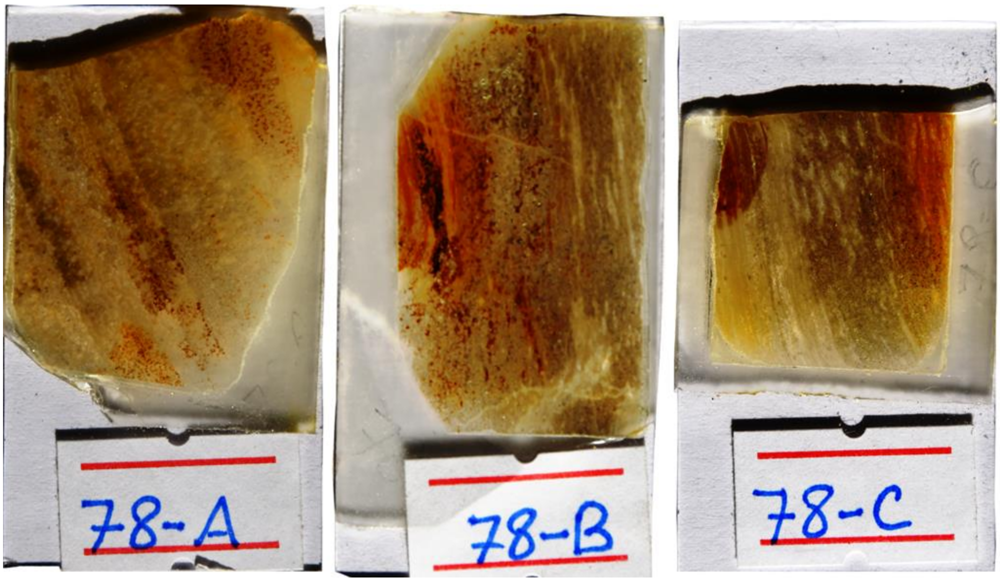


Figure 3.18 Three-dimensional thin sections i.e.(A) Transverse, (B) Radial and (C) Tangential of Wood Fossil No. 78/Man/RK/11

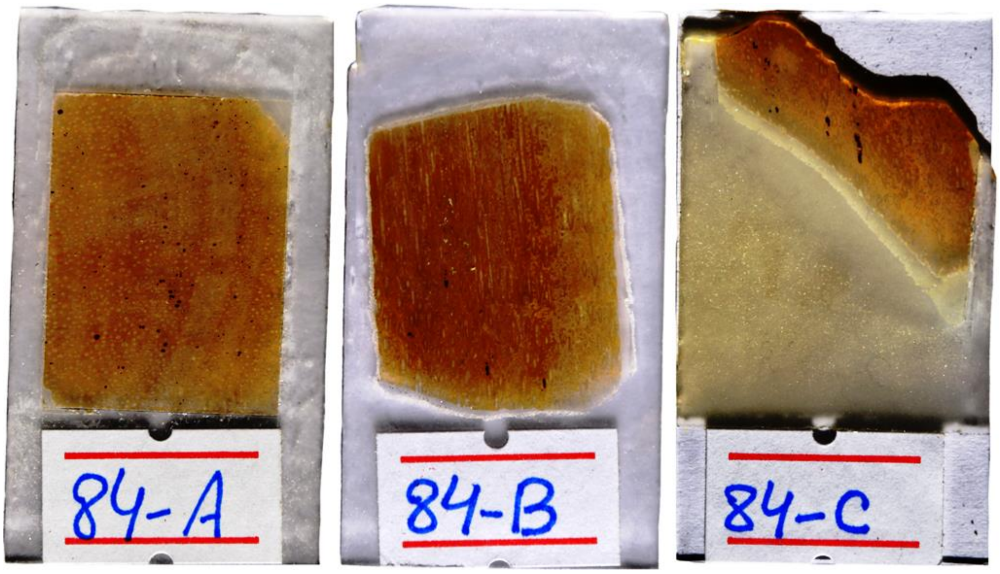


Figure 3.19 Three-dimensional thin sections i.e.(A) Transverse, (B) Radial and (C) Tangential of Wood Fossil No. 84/Man/RK/11

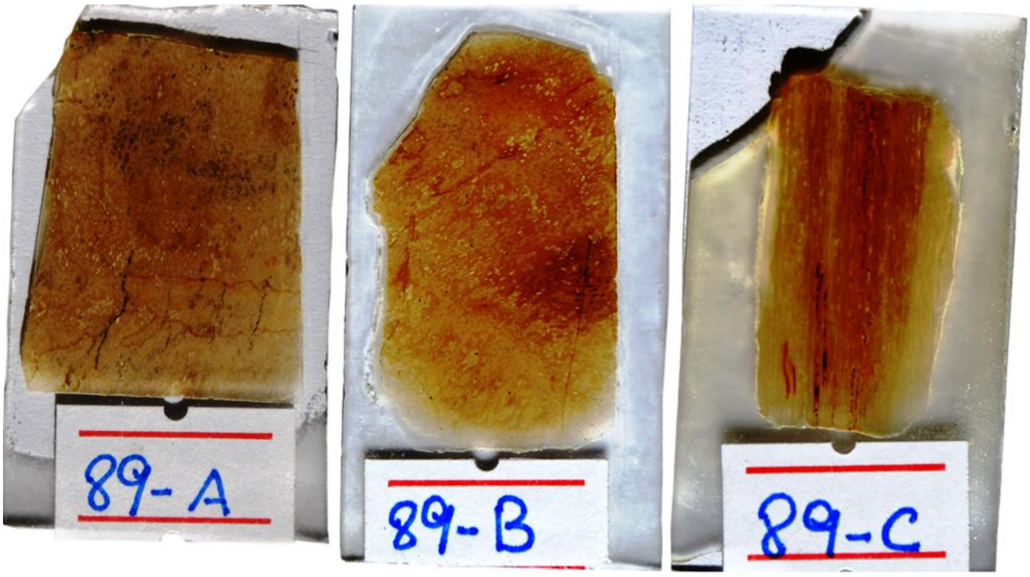


Figure 3.20 Three-dimensional thin sections i.e.(A) Transverse, (B) Radial and (C) Tangential of Wood Fossil No. 89/Man/RK/11

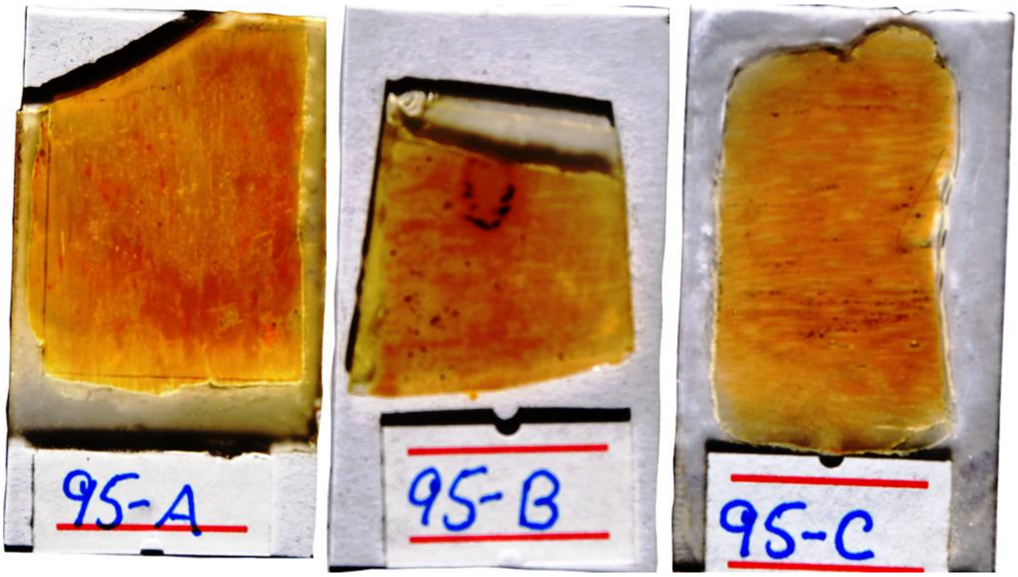


Figure 3.21 Three-dimensional thin sections i.e.(A) Transverse, (B) Radial and (C) Tangential of Wood Fossil No. 95/Man/RK/11

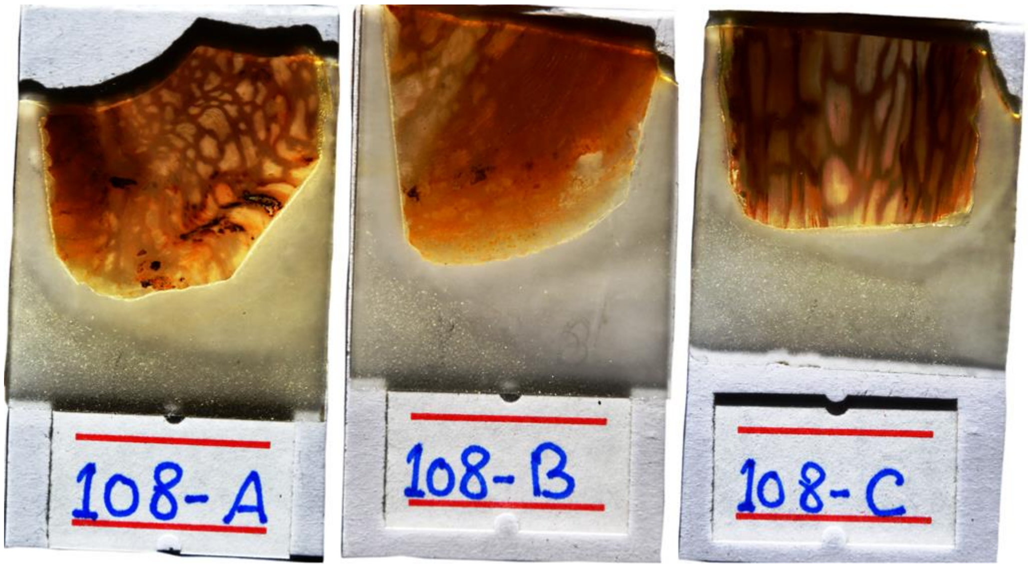


Figure 3.22 Three-dimensional thin sections i.e.(A) Transverse, (B) Radial and (C) Tangential of Wood Fossil No. 108/Man/RK/11

3.5. Anatomical Morphology

In several settings, including economic, forensic, archaeological, and paleontological, wood identification is useful (Wheeler and Baas, 1998).Sufficient fine details of original cell structure sometimes present inside the Wood Fossils which could be analyzed under the microscope. The structure of modern and fossil hardwoods and softwoods emphasizing the variable features that are useful in classifying and identifying wood(Barefoot and Hankins, 1982). Identification of a family, genus, and in certain cases, species is aided by anatomical factors such as the type of vessel, its size, how it is grouped, where parenchyma is distributed, and the size of the rays. Anatomical features of selected wood fossils specimens identified with help of (Schoch et al., 2004), *International Association of Wood Anatomists*(IAWA) and (Wheeler et al., 2020).

3.6. Identification of Wood Fossils

Anatomical features of 21 Three-Dimensional Thin Sections of 07 Wood Fossils specimens observed under the MEIJI TECHNO, Japan Polarizing Microscope Model No. MT9430 (Fig. 3.23.). Pictures of Thin sections have been taken with help of MEIJI TECHNO, Japan camera Model No. HD1500T. During observations, plan lens 4x is used (Fig. 3.24.).Observed anatomical features of 21 Three-Dimensional sections of 07 wood fossils studied with help of prescribed anatomical features prescribed by *International Association of Wood Anatomists*(IAWA) and (Wheeler et al., 2020).

Figure 3.23 MEIJI TECHNO Polarizing Microscope Model No. MT 9430

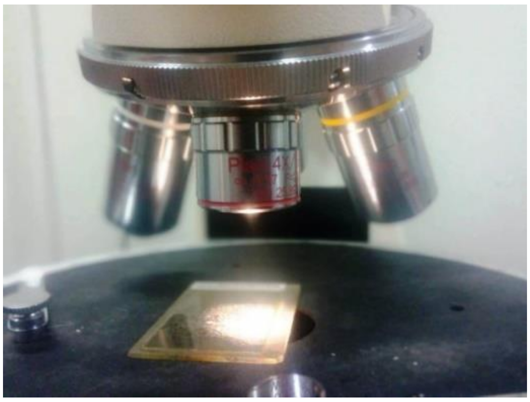


Figure 3.24 Plan 4x Lens of MEIJI TECHNO Polarizing Microscope

Anatomical observations performed with the help of available literature and digital keys and compared the 21 Three-Dimensional thin Sections with the wood fossils and present species around the world. Assistance has also been taken from the Inside Wood Project website i.e. https://insidewood.lib.ncsu.edu/search?0 to identify the wood fossils specimens (Fig. 3.25.). These works also provide extensive knowledge used for identification periodically up to the species level.

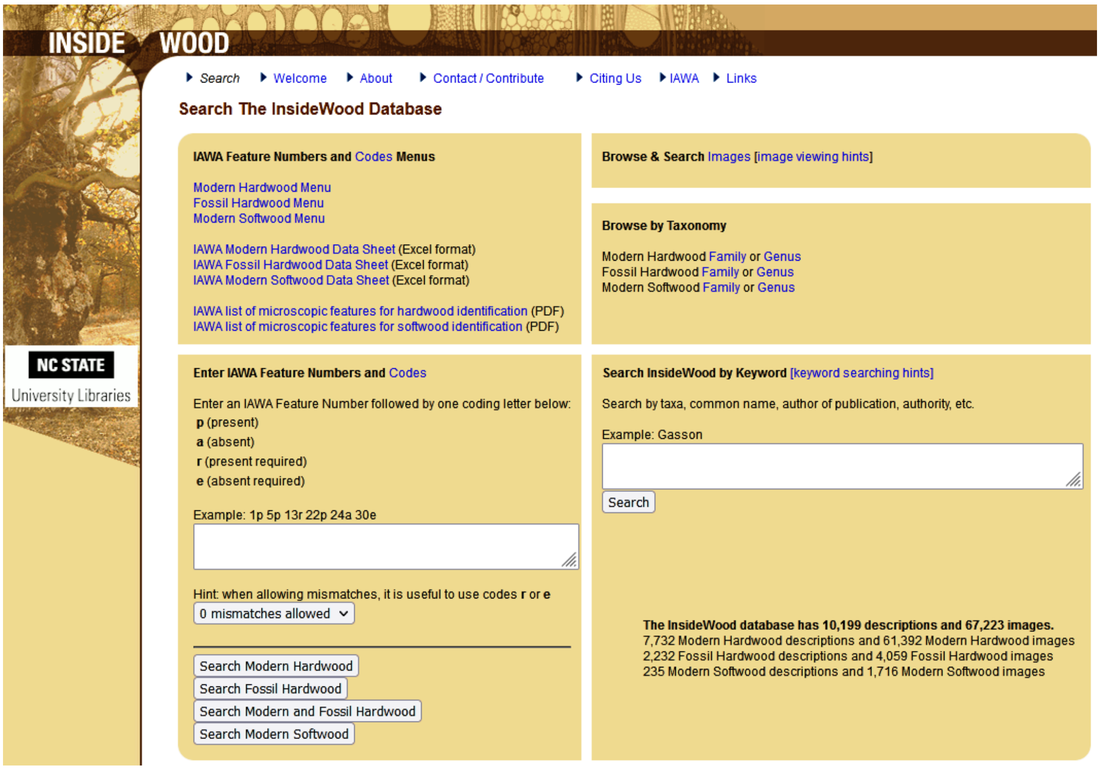


Figure 3.25 Inside Wood Project Website containing data of modern and fossil hardwood and softwood present around the world

Following software has been used for making logs, Satellite Geo-referenced map of study area and for sample locations, stratigraphic columns, and for calibrating microscopic scales;

i. Surfer® 21.1.158 for Satellite mapping (Fig. 3.26.)

ii. ImageJ 1.54c for Calibrating scale on Microscopic images (Fig. 3.27.)

iii. PSICAT 1.0.2. for making Stratigraphic Column (Fig. 3.28.)

Figure 3.26 Surfer ® 21.1.158 for satellite mapping

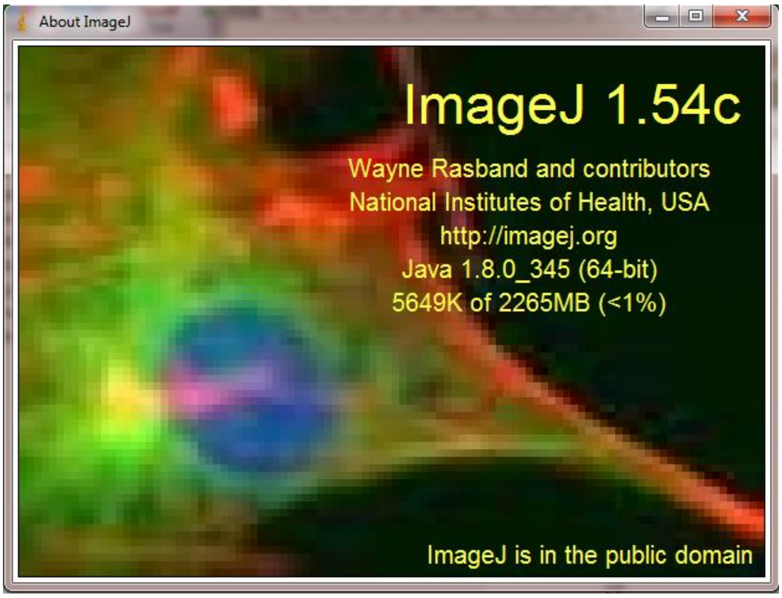


Figure 3.27 ImageJ 1.51c for calibrating scale on microscopic images

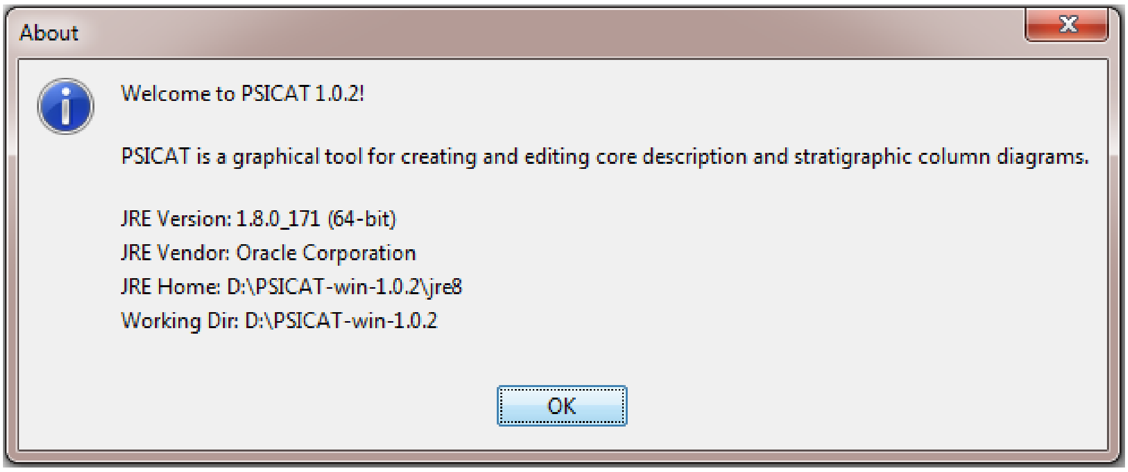


Figure 3.28 for creating and editing core description and stratigraphic column diagrams

CHAPTER 04

RESULTS AND DISCUSSIONS

Wood fossils play a major role in paleoclimatology, the study of past climates and how they changed throughout geological time. These remarkably untouched remains of old trees reveal important details about the climate fluctuations and environmental circumstances that existed while they were growing. The study of wood fossils' growth rings is one method by which they aid in the field of paleoclimatology. The age of the fossil may be ascertained and information about historical climatic conditions can be gleaned from the rings, each of which represents a year of development. Variations in temperature, precipitation, and even the duration of growing seasons can be inferred from the width and density of the rings. Scientists are able to create climate models and reconstruct historical climatic patterns by comparing these growth rings with current tree ring data.

Paleoclimatology research also makes use of stable isotopes discovered in wood remains. Scientists can deduce details like temperature, humidity, and the availability of water in the atmosphere at the time the wood was produced by examining the ratios of isotopes, such as Carbon-13 and oxygen-18. Researchers can recreate historical climate regimes and gain a deeper understanding of long-term climate trends thanks to these isotope signatures.

Additionally, wood fossils can shed light on past ecosystems' responses to climate shifts. Scientists can deduce the kinds of forests that existed over various geological periods and how they reacted to climate shifts by examining the sorts of trees preserved in the fossil record and their anatomical traits. In general, the study of wood fossils aids scientists in documenting alterations in prehistoric ecosystems, recreating past climatic conditions, and improving their understanding of long-term climate dynamics. This data is crucial for modeling future climate scenarios and projecting the potential effects of climate change on Earth.

Researchers from all over the world are reconstructing the Paleoclimate of their regions by comparing the ^{13}C isotopic fingerprints in wood fossils with the isotopes of nitrogen and oxygen. A valuable source of historical climate data is ^{13}C. With the use of this data, scientists are able to successfully compare the prehistoric and modern climates in order to make predictions about the future. There has been no attempt in Pakistan to reconstruct the Paleoclimate using carbon isotopes. The primary basis for identifying the family and genus of wood fossils nowadays is anatomical research. This paper represents a first effort to use carbon isotopic fingerprints in wood remains to reconstruct the Paleoclimate of the study region. Five of the seven specimens have been recognized as wood fossils based on microscopic investigations of anatomical traits. These characteristics, which were utilized to identify the wood fossil specimens, include vessel arrangement, porosity, vessel grouping, rays, fibers and their diameters, and other features. Anatomical analysis described following the anatomical description.

During this research work on the basis of anatomical observations, following species were identified (Table 4.1.);

Table 4:1 Identified species from wood fossil

Sr. No.	Specimen No.	Identified Family	Identified Genus	Remarks
1.	61/Man/RK/11	JUGLANDACEAE	*Caryojuglandoxylon*	Angiosperms **New Specie**
2.	77/Man/RK/11	Structures in the thin section are not visible	--	Unidentified
3.	78/Man/RK/11	Structures in the thin section are not visible	--	Unidentifiable
4.	84/Man/RK/11	LEGUMINOSAE PAPILIONOIDEAE	*Dalbergioxylon*	Angiosperms Already reported
5.	89/Man/RK/11	BETULACEAE	*Alnoxylon sp. nov*	Angiosperms **New Specie**
6.	95/Man/RK/11	SAPINDACEAE	*Aceroxylon*	Angiosperms **New Specie**
7.	108/Man/RK/11	FAGACEAE	*Castanopsis ranikotensis*	Angiosperms **New Specie**

4.1. Analysis of anatomical features

Anatomical features of petrified wood fossils analyzed under the prescribed standard features by the *International Association of Wood Anatomists* (*IAWA*) mentioned in (Table: 4.2.);

Table 4:2 Standard Anatomical Features prescribed by IAWA

Sr. No.	Anatomical Features	Description
Vessels (Pores)		
1.	**Porosity of Vessels Ring porous**	The diameter of the pores in the early wood is much greater than the diameter of the pores in the latewood.
2.	**Semi-ring porous:**	The pores in the early wood are more numerous and distinctly larger than those in the latewood. The semi-ring porous state may be induced by water-deficiency; thus this anatomic characteristic is of little value for diagnostic purposes.
3.	**Diffuse porous:**	The pores of the early wood and latewood are approximately the same size.
Grouping of Vessels		
4.	**Solitary pores:**	Pores which in general are not in contact with other pores.
5.	**Radial pore files:**	Several pores joined in radial groups, the number of pores in a group varying according to the species.
6.	**Pore cluster:**	Three or more pores irregularly grouped.
Orientation of Vessels		
7.	**Dendritic or flame like**	Flame-like, radial distribution of pores
8.	**Radial orientation**	Radial orientation of pores
9.	**Oblique orientation**	Oblique orientation of pores.
10.	**Tangential orientation**	Vessels arranged in tangential bands or grouped
Sizes of pores, Density of pores: The size and density of vessels (pores) in cross-section.		
11.	**Uniform distribution of pores.**	(Radial diameter of one pore 70-180 µm) sparsely distributed (15-25 pores/mm2).

	Large pores	
12.	**Medium-sized pores**	(Radial diameter of one pore: 50-100 µm).
13.	**Small pores**	(Radial diameter of one pore: 30-80 µm).
14.	**Very small pores**	(Radial diameter of one pore: 20-30 µm).
Tyloses: An outgrowth of an adjacent parenchyma cell through the pit cavity in a vessel wall. The vessel lumen may be obstructed.		
15.	**Gum deposits**	Tyloses can aid in the process of making sapwood into heartwood in some hardwood trees, especially in trees with larger vessels. These blockages can be used in addition to gum plugs as soon as vessels become filled with air bubbles, and they help to form stronger heartwood by slowing the progress of rot.
16.	**Tyloses with thin walls.**	
Vessels and fibers in longitudinal section		
Perforation plate:		
17.	**Simple perforation plate:**	Round to oval opening in the end wall of a vessel element.
18.	**Scalariform perforation plate:**	The round to oval opening of the end wall of a vessel element is subdivided by bars. Often all the transition forms from the simple to the scalariform perforation plates are present.
19.	**Spiral thickenings:**	Helical ridges on the internal face of the secondary wall.
20.		Spiral thickenings in fiber-tracheids.
21.		Spiral and annular cell wall thickenings in vessels of the proto- and metaxylem. These thickenings, which are found in all the species, are not useful as identification characteristics. Attention is thus necessary in the identification of twigs.
22.	**Fiber- tracheids:**	Fiber-like tracheids in the xylem with thick walls and small bordered pits (no perforation plates).
23.	**Libriform fibres:**	Fibers in the xylem with thick walls and small slit-like

		pits.
24.	**Septate fibers:**	Similar to Libriform fibres, however with thin transversal walls.
	Rays in tangential section	
25.	**Homogeneous rays:**	All cells are round or oval in form.
26.	**Heterogeneous rays:**	The margin cells are of another form than the internal, prostrate cells.
27.	**Uniseriate rays:**	Are only one cell wide.
28.	**Biseriate to triseriate rays:**	Most of the rays are 2-3 cells wide; however rare Uniseriate and 4-seriate rays are present.
29.	**Triseriate to 5-seriate rays:**	Most of the rays are 3-5 cells wide; however rare Uniseriate and Biseriate rays are present.
30.	**Storied rays:**	Rays are distributed in series at regular intervals.
31.	**Uniseriate and multi-seriate rays:**	In addition to numerous Uni-seriate rays, large rays which are visible to the naked eye are also present.
32.	**Aggregate rays:**	Group of narrow rays which to the naked eye appears as a multi-seriate ray.
33.	**Sheath cells:**	A series of upright cells bordering multi-seriate rays: In tangential section forming a sheath around the inner, prostrate cells.
34.		Ray cells enlarged at the growth ring boundary.
	Rays in radial section: The form of the ray cells is best represented in radial section.	
35.	**Homogeneous rays:**	All the ray cells are procumbent (rectangularly formed and the longest axis radially oriented). Marginal cells may be slightly modified but still procumbent in form.
36.	**Heterogeneous rays, type I:**	Procumbent cells in the interior of the rays, a one cell wide band of more or less square cells bordering the ray. This type of ray is frequent and represents the transition between homogeneous rays and truly heterogeneous rays.
37.	**Heterogeneous rays, type II:**	Procumbent cells in the interior of the rays, one row of upright cells.

38.	**Heterogeneous rays, type III:**	Procumbent cells in the interior of the ray, several rows of upright cells on the ray border.
39.		Small, numerous pits in ray-vessel intersections.
40.		Particularly large ray-vessel pits.
41.		Ray-vessel pits average size.
42.	**Development of a secondary ray:**	It is necessary to examine several rays, as in certain species the form of secondary rays differs in the initial stage and the final stage (in the initial stage the cells are frequently upright).
Parenchyma: Tissue composed of ± isodiametric cells and simple pits. **Apotracheal parenchyma:** **Axial parenchyma not in direct contact with vessels.**		
43.	**Diffuse, Apotracheal parenchyma:**	Isolated parenchyma cells, irregularly dispersed among the fibers.
44.	**Banded, Apotracheal parenchyma:**	In more or less continuous lines or tangential bands.
45.	**Paratracheal parenchyma:**	Axial parenchyma associated with vessels. Circumvascular paratracheal parenchyma: Parenchyma cells surround vessels.
46.	**Traumatic parenchyma:**	Cells of irregular size, form and distribution. Also called pith flecks.

4.2. JUGLANDACEAE Caryojuglandoxylon

4.2.1. Holotype

The sample is collected during field work from Manchar Formation of Miocene age, in the area of Ranikot, District Jamshoro, Sind Pakistan. The specimen is labeled as "61/Man/RK/11".

4.2.2. Morphological description of specimen

Selected specimen No. 61/Man/RK/11 is one piece of fairly well preserved silicified wood fossil. It is 6.5cm in height and 24.3cm in length. Fossil is dark brown in colour. 6.3cm piece from length is marked to be cut for pulverization (Fig. 3.1). Apparently fossil is light brown in colour from backside.

4.2.3. Anatomical description of specimen

There are growth rings. Wood semi-ring- permeable. One vessel as well as radially multiples of two or three vessels types holding crystal, Perforations simple, intervessel pits clustered alternating medium to big; vessel-ray parenchyma pits that resemble intervessel pits in terms of size and shape. Strands that is not septate. Axial parenchyma in the growth rings is paratracheal, scant, and distributed in narrow bands. Heterocellular, 1-3-seriate rays with 1-3 marginal rows of square-upright cells and procumbent body cells Crystals in chambered axial parenchyma threads, some crystal containing cells expanded.

Anatomical observation (Table: 4.3) shows that pores are showing Solitary nature. They distributed in a radial Flame-like pattern and they are distributed uniformly. Crystals are present. Rays in radial section showing Heterogeneous behavior (Fig. 4.1., Fig. 4.2. and Fig. 4.3).

4.2.4. Comparison with fossils and wood species affinities

The affinities with Juglandaceae are suggested by the combination of semi-ring porosity, single and short radial numerous vessels, narrow continuous lines of axial parenchyma, medium-sized alternating intervessel pits, and vessel-ray parenchyma pits that are comparable in size to intervessel pits. Furthermore, the presence of crystals and where they are located in the Juglandoideae are helpful characteristics for differentiating across genera and species groupings. This wood is different from Pterocarya and the butternut group of Juglans (the American Juglanscinerea L., 1759, generally put in section *Trachycaryon* Klotzsch, 1845, and the Asian species of Section *Cardiocaryon* Dode, 1909) because it frequently contains crystals.

Crystals seen in chambered axial parenchyma and enlarged axial parenchyma cells show connections to *Carya* and can be referred to as *Caryojuglandoxylon.* This specie is first time reported and described as new specie in Pakistan.

Hitherto, four species of *Carya* fossil wood had been described from the different localities of the world, ***Carya koreana,*** ***Carya leroyii,*** ***Carya protojaponica*** **Watari, C*aryojuglandoxylon schenkii.***

Table 4:3 Anatomical Observations of Specimen No. 61/Man/RK/11

Sr. No.	Anatomical Features	Section r radial t tangential q transversal	Diagnostic Value h high me medium mo modest	Remarks
Vessels (Pores)				
1.	**Porosity of Vessels** **Ring porous**	**q**	**h**	
2.	**Semi-ring porous:**	**q**	**m**	Present
3.	**Diffuse porous:**	**q**	**h**	----
Grouping of Vessels				
4.	**Solitary pores:**	**q**	**me**	Present
5.	**Radial pore files:**	**q**	**h**	----
6.	**Pore cluster:**	**q**	**me**	----
Orientation of Vessels				
7.	**Dendritic or flame like**	**q**	**h**	Present
8.	**Radial orientation**	**q**	**h**	----
9.	**Oblique orientation**	**q**	**h**	----
10.	**Tangential orientation**	**q**	**h**	----
Sizes of pores, Density of pores: The size and density of vessels (pores) in cross-section.				
11.	**Uniform distribution of pores.** **Large pores**	**q**	**h**	Present
12.	**Medium-sized pores**	**q**	**me**	----
13.	**Small pores**	**q**	**me**	----
14.	**Very small pores**	**q**	**h**	----
Tyloses: An outgrowth of an adjacent parenchyma cell through the pit cavity in a vessel wall. The vessel lumen may be obstructed.				
15.	**Gum deposits**	**q/r**	**me**	Crystal are present
16.	**Tyloses with thin walls.**	**q/r**	**h**	----

Vessels and fibers in longitudinal section				
Perforation plate:				
17.	**Simple perforation plate:**	**r**	**h**	Present
18.	**Scalariform perforation plate:**	**r**	**h**	
19.	**Spiral thickenings:**	**r/t**	**h**	----
20.		**r/t**	**h**	----
21.		**r/t**	**mo**	----
22.	**Fiber- tracheids:**	**r**	**h**	----
23.	**Libriform fibres:**	**r**	**me**	----
24.	**Septate fibers:**	**r**	**me**	
Rays in tangential section				
25.	**Homogeneous rays:**	**t**	**h**	Present
26.	**Heterogeneous rays:**	**t**	**h**	Present
27.	**Uniseriate rays:**	**t**	**h**	Present
28.	**Biseriate to triseriate rays:**	**t**	**h**	Present
29.	**Triseriate to 5-seriate rays:**	**t**	**-----**	----
30.	**Storied rays:**	**t**	**me**	----
31.	**Uniseriate and multi-seriate rays:**	**t**	**h**	----
32.	**Aggregate rays:**	**t/q**	**h**	Present
33.	**Sheath cells:**	**t**	**me**	----
34.		**q**	**h**	----
Rays in radial section: The form of the ray cells is best represented in radial section.				
35.	**Homogeneous rays:**	**r**	**h**	
36.	**Heterogeneous rays, type**	**r**	**me**	----

	I:			
37.	**Heterogeneous rays, type II:**	**r**	**h**	Present
38.	**Heterogeneous rays, type III:**	**r**	**h**	----
39.		**r**	**h**	----
40.		**r**	**h**	----
41.		**r**	**h**	Present
42.	**Development of a secondary ray:**	**r**	**me**	Present
Parenchyma: Tissue composed of ± isodiametric cells and simple pits. Apotracheal parenchyma: Axial parenchyma not in direct contact with vessels.				
43.	**Diffuse, Apotracheal parenchyma:**	**q**	**Me**	
44.	**Banded, Apotracheal parenchyma:**	**q**	**h**	Present
45.	**Paratracheal parenchyma:**	**q**	**h**	----
46.	**Traumatic parenchyma:**	**q**	**me**	----

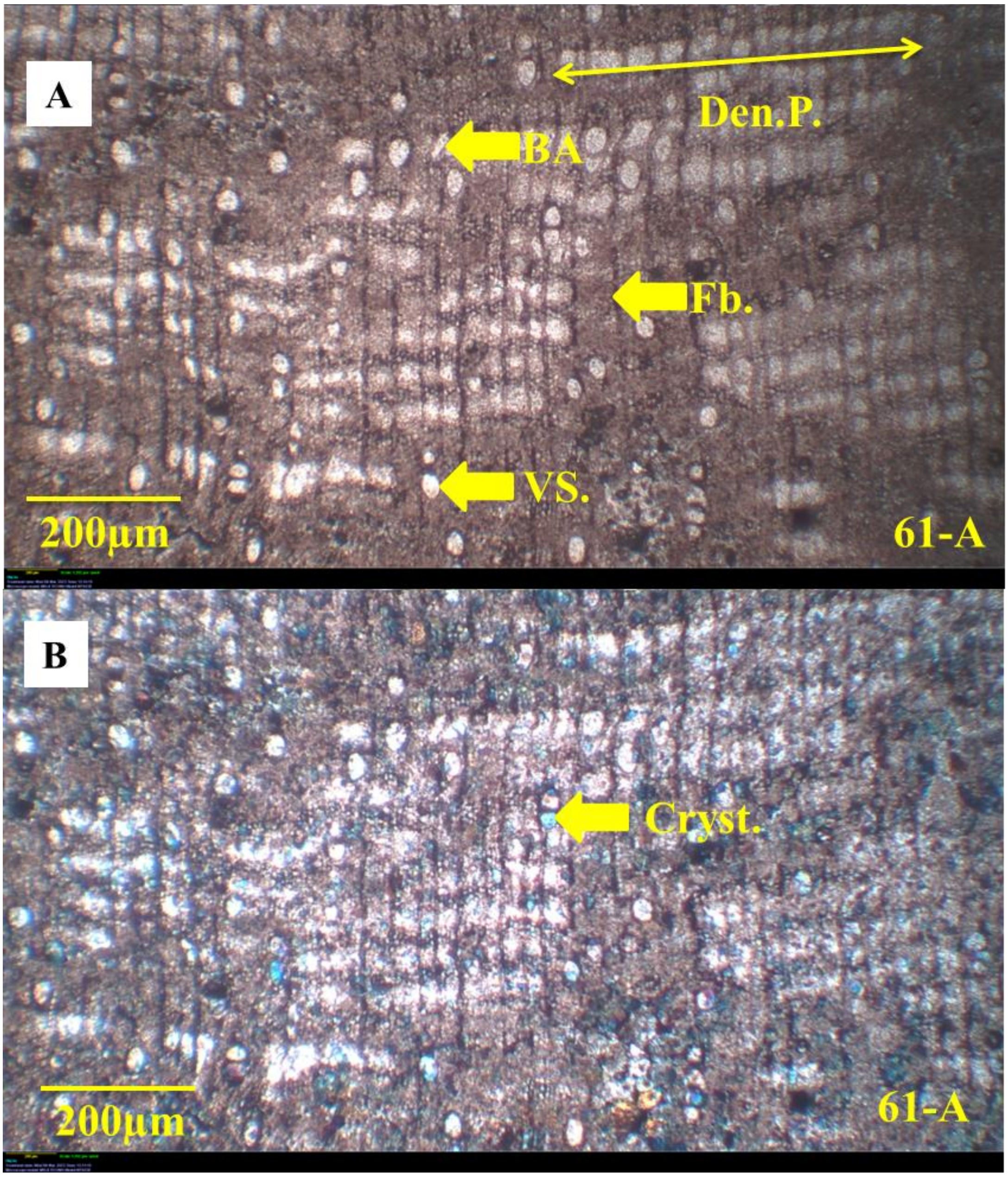


Figure 4.1 Transverse Thin Section of Specimen 61/Man/RK/11 showing distribution of pores and their nature

A)	**De.P. :**	**Dendritic Pattern**
	BA.:	**Banded Apotracheal**
	Fb.:	**Fibers**
	VS.:	**Vessels Solitary**
	Cryst.:	**Crystals**

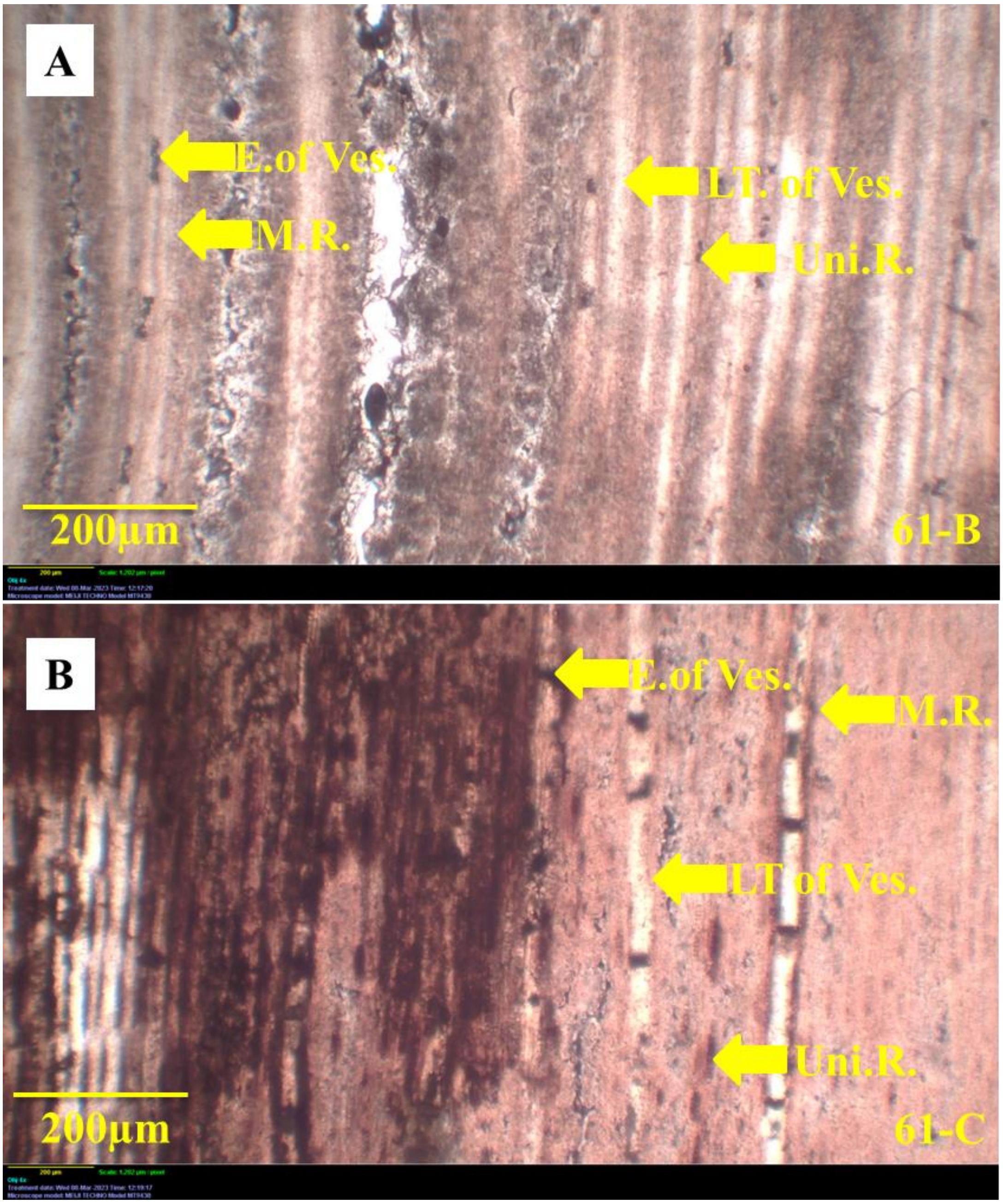


Figure 4.2 A) Radial and B) Tangential Thin Section of Specimen 61/Man/RK/11 showing arrangement of Vessels and Fibers;

A) and B)	**E. of Ves.:**	**End of wall of Vessel**
	LT. of Ves.:	**Long Tube of Vessels**
	M.R.:	**Multiseriate Rays**
	Uni.R.:	**Uniseriate Rays**

4.2.5. Affinities of fossil with other wood fossils in the world

(Jeong, 2009) collected 38 instances of well-preserved wood fossils from the Lower Coal-bearing Formation of the Janggi Group in Donghae-myeon, Pohang City, Gyeongsangbuk-do Prefecture, Korea. He discovered fourteen distinct wood fossil species from seven families and eleven genera. He identified and described seven new taxa: *Acer minokamoensis* Jeong, Kim et Suzuki; ***Caryakoreana*** **Jeong** et Kim; *Betulajanggiensis* Jeong et Kim; *Carpinusdonghaensis* Jeong et Kim; *Ostryageum-gwangensis*Jeong et Kim; *Stewartia pseudo-camellioxylon* Jeong et Kim. *Wataria*, *Aceraceae*, *Ulmaceae*, and *Betulaceae* are the most prevalent taxa. With the possible exception of *Wataria*, whose preferred environment is unknown, these taxa, which resemble the *Aniai* type of Japanese flora, are significant constituents of cool-temperate vegetation. According to earlier studies of fossil plants from the Yeonil Group (leaves and seeds), the Upper Coal-bearing Formation (fossil forests), and the Geumgwangdong Shale (leaves and seeds), the Pohang Basin's temperature evolved from cool-temperate to warm-temperate and subtropical during the Miocene.

(Wheeler, E. A. 2023) worked on 36 million yr old well-preserved silicified wood specimens from Pacific Northwest, USA and found species belonging to the families Pinaceae (*Keteleeriafarjonii* sp. nov.), Cupressaceae(*Taxodioxylon* sp.), Magnoliaceae (*Magnolia hansnooteboomii* sp. nov.), Lauraceae (*Laurinoxylon* sp. A and B),Platanaceae (*Platanoxylonhaydenii* (Felix) Süss and Müller-Stoll, 1977), Fabaceae (*cf. Styphonolobium* sp.),Fagaceae (*Fagusdodgei* Wheeler and Manchester, 2021, Quercus sp., Red Oak type), **Juglandaceae (*Caryaleroyii* sp. nov.),**Ulmaceae (Ulmuswoodii Wheeler and Manchester, 2007), Sapindaceae (*Aesculusconstabularisii* sp. nov., *Klaassenoxylon wilkinsonii* gen. et sp. nov.), and Araliaceae (*Plerandreoxylon oskolskii* sp. nov.).These forests, along with species found in nearby seeds and fruits that have become silicified, include a varied group of woody plants that range from warm temperate to subtropical, some of which have East Asian connections. By contrasting the wood functional characteristics of the Dietz Hill assemblage with those of the younger woods connected to the Oligocene Bridge Creek flora and the older Clarno Nut Beds (mid-Eocene) woods, it is possible to demonstrate increased seasonality and a cooling environment.

(Selmeier, 1986), reported the presence of Genus of fossil wood from the publication of Felix (1882) which includes *Tempskya*an extinct fern genus (Holleis and Gregor 1986);Taxodiaceae; Dipterocarpaceae, Ebenaceae, Fagaceae, **Juglandaceae**, Lauraceae, Leguminosae, Platanaceae, Rosaceae, Sapotaceae, Ulmaceae; Arecaceae (*Palmae*). It is necessary to include the current wood sample, which was recognized as Pistacia, Anacardiaceae, and reported from Southern Franconian Alb, Bavaria.

4.2.6. Comparison with modern wood species and affinities

Wood Taxonomists examined physical characteristics the extinct species is a member of the family JUGLANDACEAE *Caryojuglandoxylon* and compared its characteristics with the modern species and reported many species of the Modern species belong to the family JUGLANDACEAE. Following is the brief of some of the genus related to the Wood Fossil specimen (Table: 4.4);

Table 4:4 On the basis of anatomical features of specimen 61/Man/RK/11, the following modern species reported in the world belong to the same genus

Sr. No.	Name of Family	Genus	Regions Habitat	Age	Geographical Distribution	Reference
1.	**JUGLANDACEAE**	*Caryaaquatica* (F. Michx.) Nutt. (BITTER PECAN, WATER HICKORY)	--	Present	--	--

2.	**JUGLANDACEAE**	*Caryacathayensis* Sarg.	Tree (30m tall)	Present	Asia that is temperate and Europe Russia, Japan, and China in temperate Asia	(Itoh, 1995))
3.	**JUGLANDACEA E**	*Caryacordiformis* (Wangenh.) K.Koch (BITTERNUT HICKORY)	Deciduous	Present	--	(Wheeler et al., 2020)
4.	**JUGLANDACEAE**	*Caryafloridana*Sarg. (SCRUB HICKORY)	Deciduous	Present	--	(Wheeler et al., 2020)
5.	**JUGLANDACEA E**	[illegible] (Mill.) Sweet (PIGNUT HICKORY, SWEET PIGNUT HICKORY)	Deciduous	Present	North America, north of Mexico	(Stark, E.W., 1953)
6.	**JUGLANDACEAE**	*Caryaillinoinensis* (Wangenh.) K.Koch (PECAN)	Deciduous Cultivated	Present	North America, north of Mexico	(Stark, E.W., 1953b)
7.	**JUGLANDACEAE**	*Caryalaciniosa* (F.Michx.) G.Don (SHELLBARK HICKORY)	Deciduous	Present	North America, north of Mexico	(Stark, E.W., 1953b)

8.	**JUGLANDACEAE**	*Caryaovata* (Mill.) K.Koch (SHAGBARK HICKORY)	Deciduous	Present	North America, north of Mexico	(Wheeler et al., 2010)
9.	**JUGLANDACEAE**	*Caryaovata* (Mill.) K.Kochvar. *australis*	Deciduous	Present	North America, north of Mexico	(Wheeler et al., 2010)
10.	**JUGLANDACEAE**	*Caryapallida* (Ashe) Engelm. andGraebn. (PIGNUT HICKORY)	principally east of Mississippi River, U.S.: (see Flora of North America) Deciduous	Present	North America, north of Mexico	(Wheeler et al., 2010) (Stark, E.W., 1953b)
11.	**JUGLANDACEAE**	*Caryasinensis* Dode	--	Present	Asia-Pacific and Southeast Asia Vietnam, Cambodia, Laos, Thailand (Indochina)	(Leroy, J.F., 1953)
12.	**JUGLANDACEAE**	*Carya SPP*. (TRUE HICKORY)	--	Present	North America, north of Mexico	(Stark, E.W., 1953b)
13.	**JUGLANDACEAE**	*Caryatexana*	--	Present	--	--

4.2.7. PALEOCLIMATOLOGY

On the basis of sedimentological research, it concludes that the sediment source for the Manchar formation is in the western highlands and that the formation was deposited in both marginal marine and fluvial environments (MH Agheem et al, 2016). The Pohang Basin's climate is thought to have changed from cool-temperate to warm-temperate and subtropical during the Miocene, according to previous studies of fossil plants from the Yeonil Group (leaves and seeds), the Upper Coal-bearing Formation (fossil woods), and the Geumgwangdong Shale (leaves and seeds) (Jeong, 2009). Wood fossils from the Lower Coal-bearing Formation of the Janggi Group in Donghae-myeon, Pohang City, Gyeongsangbuk-do Prefecture, Korea, served as the basis for these conclusions. (Wheeler et al., 2023) also suggested that (Wheeler et al, 2023) research on the wood fossils collected from the Pacific Northwest, USA, also suggested that these forests include a varied group of woody plants that range from warm temperate to subtropical, some of which have East Asian connections, along with species found in nearby seeds and fruits that have become silicified. Present environment of Ranikot area where Manchar Formation and other sequences are found is barren in present time. A specimen of wood fossil, identified as belonging to the JUGLANDACEAE family Based on current global Hardwood species, *Caryojuglandoxylon* offers proof of the presence of a "Deciduous Forest" during the Miocene in the studied region (Table: 4.4).

Nowadays, deciduous forests can be found all over the world in tropical and temperate regions. Broad, flat leaves that absorb a lot of light and demand a lot of water are characteristic of deciduous trees. Most prominent feature of deciduous forest is that once in a year, deciduous trees shed their leaves due to the changes in the environmental/climatic conditions. In autumn, due to reduction in the process of Photosynthesis because of less sunlight, deciduous trees and other plants undergoes some physical changes which leads to the pause in chlorophyll production and turn their colour brown and make them dried. When plenty of rain fall is available which ranges from 750 to 1500 mm (30-60 inches)(Allaby, 2006), and days become warmer in the Spring and Summer times, they start to grow their leaveswhen an average yearly temperature of 20^{o}C and a range of 18 to 30^{o}C, the growth season is excellent (Allaby 2006). This area has four distinct seasons since the deciduous forest areas are exposed to both warm and cold air masses. The temperature varies significantly throughout the year, with hot, muggy summers and chilly winters. The average yearly temperature is approximately 10°C.

Deciduous temperate forests are found in the cool, moist parts of the northern hemisphere (North America, which includes Canada, the United States, and central Mexico), Europe, and western Asia, which includes parts of Russia, Japan, China, North Korea, South Korea, and Korea). There are also a few minor deciduous forest regions in the southern hemisphere, which includes Australia, South America, and Africa.

Presence of JUGLANDACEAE *Caryojuglandoxylon* in is the clear evidence of change in the environment with the passage of time.

4.3. LEGUMINOSAEPAPILIONIDEAE *Dalbergioxylon*

4.3.1. Holotype

The sample is collected during field work from Manchar Formation of Miocene age, in the area of Ranikot, District Jamshoro, Sind Pakistan. The specimen is labeled as "84/Man/RK/11".

4.3.2. Morphological description of specimen

Selected specimen No. 84/Man/RK/11 is one piece of fairly well preserved silicified wood fossil. It may be the piece of part of the stem. It is 6.5cm in height and 24 cm in length. Fossil is dark brown in colour from the front and light yellowish brown in colour from backside.5.5cm piece from length is marked to be cut for pulverization (Fig. 3.4).

4.3.3. Anatomical description of specimen

Diffuse-porous wood, solitary and in radial multiple vessels, exclusively simple perforation plates, short-medium vessel element lengths, alternate vessel pitting, non-septate fibers, primarily paratracheal, combinations of aliform, confluent, parenchyma, and uniseriate to multiseriate rays are among the most significant anatomical features of the current fossil wood (Fig. 4.4a and4.4b., Fig. 4.5., and Fig. 4.6). These features are also present in tropical legumes (Fabaceae), as well as in *Bignoniaceae, Meliaceae, Moraceae*, and tropical Sapindaceae. However, only the Fabaceae family has vestured pitting among the aforementioned families (Wheeler and Baas, 1992). Applying the Müller-Stoll and Mädel (1967) identification key for the genera of ancient legume woods, *Dalbergioxylon* may be identified. Its characteristics include diffuse-porous wood, non-Septate fibers, up to three seriate rays, and aliform or often confluent parenchyma with irregular tangential bands (Table: 4.5).

Table 4:5 Anatomical Observations of Specimen No. 84/Man/RK/11

Sr. No.	Anatomical Features	Section r radial t tangential q transversal	Diagnostic Value h high me medium mo modest	Remarks
Vessels (Pores)				
1.	**Porosity of Vessels** **Ring porous**	**q**	**h**	Present
2.	**Semi-ring porous:**	**q**	**me**	
3.	**Diffuse porous:**	**q**	**h**	-----
Grouping of Vessels				
4.	**Solitary pores:**	**q**	**me**	Present
5.	**Radial pore files:**	**q**	**h**	----
6.	**Pore cluster:**	**q**	**me**	----
Orientation of Vessels				
7.	**Dendritic or flame like**	**q**	**h**	Present
8.	**Radial orientation**	**q**	**h**	----
9.	**Oblique orientation**	**q**	**h**	----
10.	**Tangential orientation**	**q**	**h**	----
Sizes of pores, Density of pores: The size and density of vessels (pores) in cross-section.				
11.	**Uniform distribution of pores.** **Large pores**	**q**	**h**	Present
12.	**Medium-sized pores**	**q**	**me**	Present
13.	**Small pores**	**q**	**me**	----
14.	**Very small pores**	**q**	**h**	----
Tyloses: An outgrowth of an adjacent parenchyma cell through the pit cavity in a vessel wall. The vessel lumen may be obstructed.				
15.	**Gum deposits**	**q/r**	**me**	

16.	**Tyloses with thin walls.**	**q/r**	**h**	----
Vessels and fibers in longitudinal section				
Perforation plate:				
17.	**Simple perforation plate:**	**r**	**h**	Present
18.	**Scalariform perforation plate:**	**r**	**h**	----
19.	**Spiral thickenings:**	**r/t**	**h**	Present
20.		**r/t**	**h**	----
21.		**r/t**	**mo**	----
22.	**Fiber- tracheids:**	**r**	**h**	----
23.	**Libriform fibres:**	**r**	**me**	----
24.	**Septate fibers:**	**r**	**me**	Present
Rays in tangential section				
25.	**Homogeneous rays:**	**t**	**h**	Present
26.	**Heterogeneous rays:**	**t**	**h**	----
27.	**Uniseriate rays:**	**t**	**h**	Present
28.	**Biseriate to triseriate rays:**	**t**	**h**	----
29.	**Triseriate to 5-seriate rays:**	**t**	**-----**	Present
30.	**Storied rays:**	**t**	**me**	----
31.	**Uniseriate and multi-seriate rays:**	**t**	**h**	Present
32.	**Aggregate rays:**	**t/q**	**h**	----
33.	**Sheath cells:**	**t**	**me**	----
34.		**q**	**h**	----
Rays in radial section: The form of the ray cells is best represented in radial section.				
35.	**Homogeneous rays:**	**r**	**h**	Present
36.	**Heterogeneous rays, type I:**	**r**	**me**	----
37.	**Heterogeneous rays, type II:**	**r**	**h**	----
38.	**Heterogeneous rays, type III:**	**r**	**h**	----
39.		**r**	**h**	----
40.		**r**	**h**	----
41.		**r**	**h**	----
42.	**Development of a secondary ray:**	**r**	**me**	Present

Parenchyma: Tissue composed of ± isodiametric cells and simple pits. **Apotracheal parenchyma:** **Axial parenchyma not in direct contact with vessels.**				
43.	**Diffuse, Apotracheal parenchyma:**	**q**	**Me**	Present
44.	**Banded, Apotracheal parenchyma:**	**q**	**h**	----
45.	**Paratracheal parenchyma:**	**q**	**h**	Present
46.	**Traumatic parenchyma:**	**q**	**me**	----

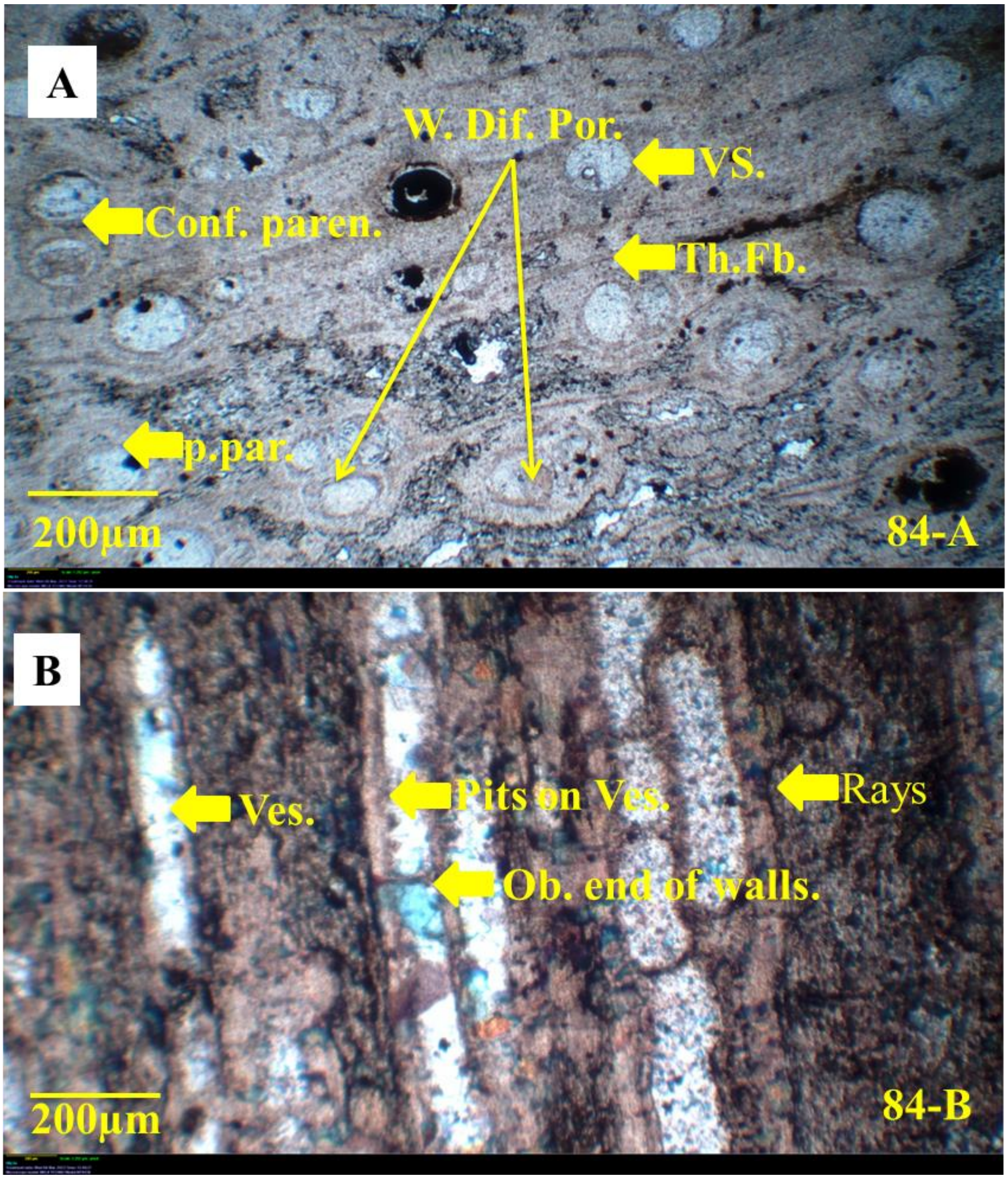


Figure 4.3 A) Transverse and B) Radial Thin Section of Specimen 84/Man/RK/11 showing distribution of pores and their nature:

A)		**W. Dif. Por.:**	**Wood Diffuse Porous**
		VS.:	**Vessels Solitary**
		Conf. paren:	**Confluent parenchyma**
		Th.Fb.:	**Thick Fibers**
		p.par.:	**Paratracheal parenchyma with aliform arrangement**
	B)	**Rays:**	**Rays**
		Ves.:	**Vessels**
		Ob. end of walls:	**Oblique end of wall**
		Pits on Ves.:	**Pits on Vessels**

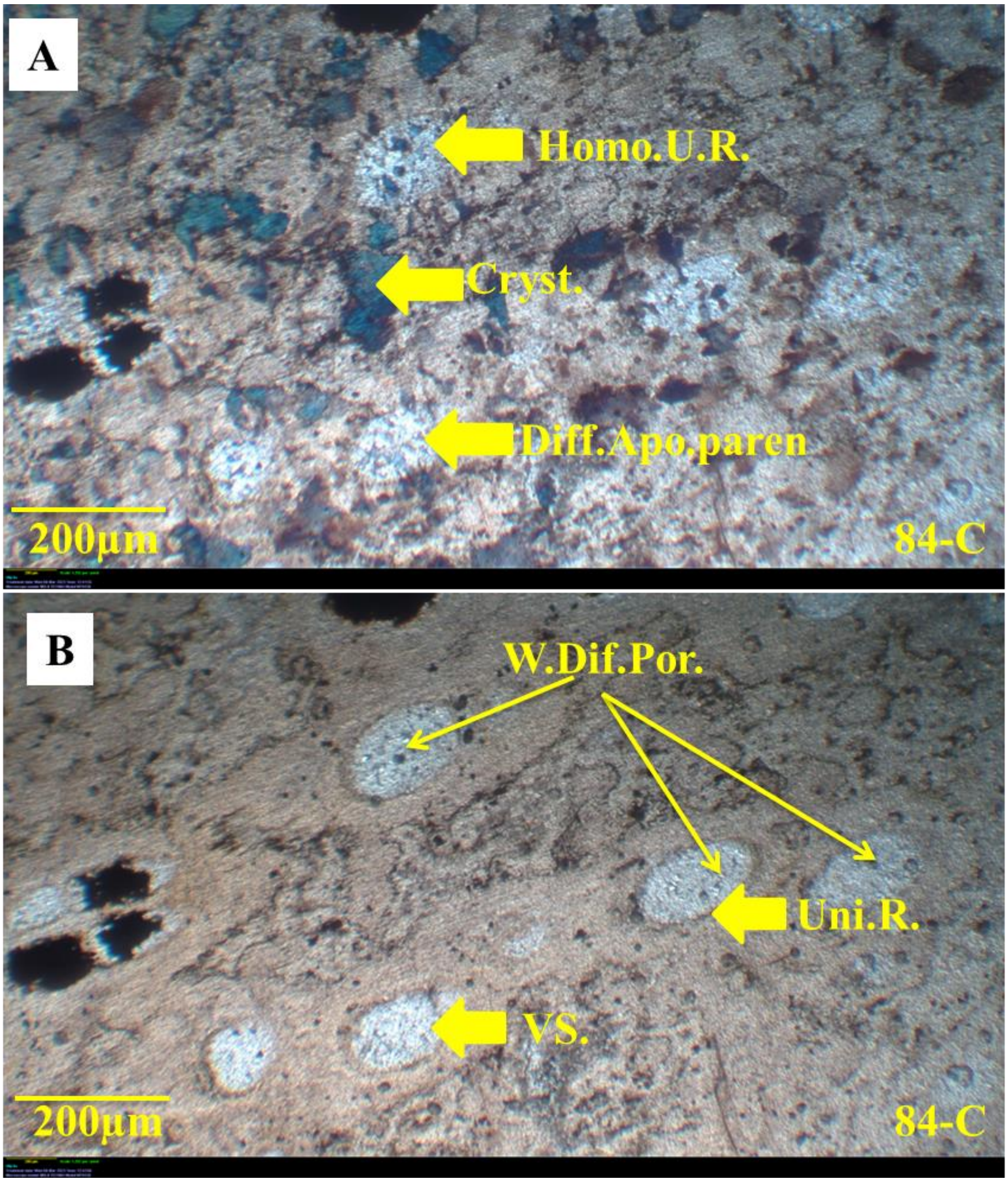


Figure 4.4 Tangential Thin Section of Specimen 84/Man/RK/11 showing distribution of pores and their nature in A) Cross polarized light image B) Plan polarized light image:

A)	**Homo.U.R.:**	**Homogeneous Uniseriate rays**
	Cryst.:	**Crystals**
	Diff.Apo.paren:	**Diffuse, Apotracheal parenchyma**
B)	**W.Dif.Por.:**	**Wood Diffuse Porous**
	Uni.R.:	**Uniseriate Rays**
	VS.:	**Vessels Solitary**

4.3.4. Comparison with fossils wood species and affinities

Five species of the genus *Dalbergioxylon* have been identified in Africa, Asia, and Europe spanning the Oligocene to Miocene/Pliocene (Gregory et al., 2009; Tiwari et al., 2012): Dicorynioides from the Pliocene/Miocene of India (Ramanujam, 1960), and *Dalbergioxylon antiquum* from Five species of the genus *Dalbergioxylon* have been identified throughout Africa, Asia, and Europe, from Oligocene to Miocene/Pliocene (Gregory et al., 2009; Tiwari et al., 2012). These species include *Dalbergioxylon antiquum* from the Oligocene of Tunisia (Fliche, 1888) to the Miocene/Pliocene of India (Ramanujam, 1960), and Dicorynioides from Oligocene and Oligocene/Miocene of Egypt (Kräusel, 1939; El-Saadawi et al., 2011). Four species of D. *mizoramensis* from Miocene/Pliocene of India (Tiwari 2012), five species from the Pliocene of Africa (Burgh, 1973), and three species of D. *europaeum* from Miocene of African Miocene dicot woods identified by wood anatomists (Table: 4.6).

Table 4:6 On the basis of anatomical features of specimen No. 84/Man/RK/11the following wood fossil species reported in the world belongs to the same genus

Sr. No.	Name of Family	Genus	Region Habitat	Age	Geographical Distribution	Reference
1.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergioxylon antiquum*Ramanujam	South India	Miocene (Upper) Pliocene (Lower)	Central South Asia	Ramanujam, C. G. K. (1960).

2.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergioxylon biseriatensis* Cheng, Wang, Liu, Jin, Mehrotra, Jiang and Li	China's Yuanmou County, Wanpu and Guanghui Clay Forests, lower portion of the Yuanmou Formation	Pliocene	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Cheng, Y. M., 2018)
3.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergioxylon dicorynioides* Müller-Stoll andMädel	--	Miocene	Europe and temperate Asia Mediterranean including Northern Africa and Middle East	(El-Saadawi, 2011)
4.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergioxyloneuropaeum*Burgh	--	Miocene	Europe and temperate Asia Europe, excluding Mediterranean	(Van Burgh, 1973)
5.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergioxylon oligocenicum*Dupéron	Agenais, France	Eocene (Upper)	Europe and temperate Asia Europe, excluding Mediterranean Mediterranean including Northern Africa and Middle East	Dupéron, J. (1979).

(Cheng, M., Y., 2018) gathered Cenozoic wood fossil species from the Yunnan Basin, which is located close to the southeast of the Qinghai-Tibet Plateau in China. Sediments of Yunnan Basin are fluvial-lacustrine in nature. Cheng, Y., M. (2018) describes ten angiosperm taxa and three gymnosperm taxa. These include *Cedreloxylon* cristalliferum Selmeier (Meliaceae), *Dalbergioxylon biseriatensis* sp. nov. (Fabaceae), *Lagerstroemioxylon yuanmouensis*, and *Castanopsismakinoi* (Ogura) Suzuki and Terada (Fagaceae). Cheng, Li, Jiang and Wang (Lythraceae), *Paraalbizioxylon sinica* sp. nov., P. *yunnanensis* sp. nov. (Fabaceae), *Pterocaryoxylon huxii* sp. nov. (Juglandaceae), Zelkovawakimizui (Watari) *Watari* (Ulmaceae), *Abies* sp. (*Pinaceae*), *Cephalotaxus sp*. (*Cephalotaxaceae*), and Picea sp.

(Cheng, Y, M. 2018), also linked identified wood fossils species with Nearest Living Relative (NLR) and compared them with previously identified taxa and proposed that during Pliocene time. Additionally, he argued that species from the genera *Pterocarya* / *Juliens*, *Albizia* / *Acacia, Bischofia*, and associated species were found in lower elevations of subtropical evergreen and deciduous mixed broad-leaved forests. Whereas the evergreen coniferous forest of *Abies*, *Picea*, and other genera is found at higher heights of the mountains, the subtropical evergreen broad-leaved forest, dominated by *Quercus / Lithocarpus* and *Castanopsis*, is found at moderate altitudes of the mountains encircling the basin. On basis of Nearest Living Relatives (NLRs) Cheng proposed that the predominant climate was probably humid subtropical, as opposed to the hot, dry climate of today that sustains savanna. Some hypotheses state that during this time, subtropical woods dominated Yunnan, whereas tropical rain forests existed in southwest Asia and India. The elevated mountains of the Qinghai-Tibet plateau in western Yunnan probably acted as a barrier to exclude warm, humid air from the Indian Ocean, which had an impact on plant dispersal and distribution.

(Van Burgh, 1973) collected 41 wood fossil species from various brown coal pit locations, including "Maria Theresia" at Herzogenrath, "Zukunft West" at Eschweiler, "Victor" at Zülpich (ZülpichMitte), and the clay pit "Fischer" at Adendorf, Netherlands. The genus Pinus was systematically revised based on anatomical and morphological features. He listed twenty-three species of conifer hard wood, such as *Juniperoxylon rhenanum*, *Piceoxylon rhenanum, P. megapolitanum, P. eschweilerense*, and *Pinuxylon halepensoides*. He found 18 species of angiosperms wood of *Magnolioxylon parenchymatosum, Dalbergioxylon europaeum, Ternstroemioxylon adenorfense, Fagoxylon crystallophorum, Castanoxylon eschweilerense, Hamamelidoxylon rhenanum, Symplocoxylon eschweilerense* and *Tilioxylon palaeocordatum.* He recreated the Paleoclimatic conditions based on these newly identified wood fossil species, and discovered that open mixed woodland with vegetation consisting of conifers and angiosperms existed at that time. Though wetter, the climate was only somewhat warmer than it had been recently in Cologne.

4.3.5. Comparison with modern wood species and affinities

Physical attributes of the extinct species in the family **LEGUMINOSAEPAPILIONIDEAE** and its' genus ***Dalbergioxylon*** were examined by Wood Taxonomists. *Dalbergioxylon* and matched its traits with those of the contemporary species, revealing that many of the latter are members of the LEGUMINOSAEPILIONDEAE family. The genera that are briefly mentioned about the Wood Fossil specimen are listed below (Table: 4.7);

Table 4:7 On the basis of anatomical features of specimen 84/Man/RK/11 the following modern species reported in the world belong to the same genus

Sr. No.	**Name of Family**	**Genus**	**Region Habitat**	**Age**	**Geographical Distribution**	**Reference**
1.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergiaassamica* Benth. (ROSEWOOD, YANG QING)	[Chinese flora] Mixed forests, open forests, among shrubs, mountain slopes, riverbanks, wastelands next to communities; 300–1700 m; 7–10 m tall	Present	Central Asia **Pakistan**, India, and Sri Lanka Myanmar Asia-Pacific and Southeast Asia Vietnam, Cambodia, Laos, Thailand (Indochina)	(Wheeler et al, 2007)

2.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergiabaronii* Baker (MADAGASCAR ROSEWOOD, PALISANDER)	Lowland evergreen, Deciduous, humid rainforest eastern Madagascar **IUCN Red List of Threatened Species listing them as vulnerable**	Present	Tropical continent Africa, including Madagascar, Mauritius, Réunion, and Comores, as well as nearby islands	(Lemmens, R.H.M.J., 2007)
3.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergiabracteolata* Baker (FELANGOAKA, VAHINTA)	--	Present	Tropical continent Africa, including Madagascar, Mauritius, Réunion, and Comores, as well as nearby Islands	--
4.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergiacearensis* Ducke (VIOLETTA)	--	Present	Both temperate and neo-tropical Brazil in South America's Tropics	(Gasson et al, 2010)

5.	**LEGUMINOSAE PAPILIONOIDEAE**	*Dalbergiachapelieri* Baill.	Madagascar	Present	Tropical continent Africa, including Madagascar, Mauritius, Réunion, and Comores, as well as nearby Islands	(Detienne, P.)

4.3.6. PALEOCLIMATOLOGY

A sedimentological study revealed that the Manchar formation was formed in both marginal marine and fluvial environments, with the western highlands serving as the formation's sediment supply (MH Agheem et al, 2016).(Cheng, Y, M. 2018) described the environment of Pliocene of study areas most likely humid subtropical which differentiate it today's dry environment. He marked the existence of subtropical forests which predominated in Yunnan. (Van Burgh, 1973), predicted wetter climate in Cologne, Netherland during Miocene on the basis of Conifers and angiosperms species he collected from the study area. Presently, more modern species linked with this fossil hard wood family and genus reported around the world in the different part of Sri Lanka, Pakistan, India, Burma, Southeast Aisa, Pacific Thailand, Loas Vietnam, Cambodia alongside mountains slope, riverside, low land, evergreen, deciduous and humid rain forests. These genera are composed on tall trees. Their past existence and present location in the different areas of the world indicates the change in environment with the time. Presently 300 modern species of this genus are found in the tropics and subtropics. Tropical weather characterized by consistently high temperatures and little seasonal fluctuation. These areas have high levels of humidity and rainfall, with different seasons that come and go. Diverse ecosystems include those with lush foliage, a wide variety of plant and animal species, and tropical rain forests. While a subtropical climate is often colder than a tropical one, but warmer than a temperate one. Greater seasonal variance in temperature with warm to hot summers and mild winters could be seen. Compared to tropical regions, there are moderate to high humidity levels, erratic rainfall patterns, and fewer distinct wet and dry seasons. When compared to tropical rainforests, the diversity of vegetation in subtropical forests and grasslands can be lower.

Specimen No. 84/Man/RK/11 which is identified as a **LEGUMINOSAEPAPILIONIDEAE *Dalgergioxylone*** collected from the Manchar Formation which Miocene in age, belongs to the modern specie *Dalbergiasissoo*, commonly known North Indian rosewood or "**Shisham"**. Rosewood is slow-growing specie. According to estimate, tree takes 70-100 years to grow a size where they can produce a reasonable amount of heartwood (Lemmens, 2008). Presently, Shisham mainly found in Punjab and Khyber Pakhtunkhwa. Presence of *Dalbergioxylon wood fossils* (Shisham) in Ranikot barren area is a clear indication of change in environment.

4.4. BETULACEAE *Alnoxylon sp. nov* (New Specie)

4.4.1. Holotype

The sample is collected during field work from Manchar Formation of Miocene age, in the area of Ranikot, District Jamshoro, Sind Pakistan. The specimen is labeled as "89/Man/RK/11".

4.4.2. Morphological description of specimen

Selected specimen No. 89/Man/RK/11 is one piece of fairly well preserved silicified wood fossil. It seems to be a piece of stem. It is 6.5cm in height and 19.6cm in length. 5.5cm piece from length is marked to be cut for pulverization (Fig. 3.5). Fossil is yellowish brown in colour. Apparently fossil is light brown to grayish in colour from backside.

4.4.3. Anatomical description of specimen

Transverse, Radial and Tangential thin sections of specimen 89/Man/RK/11 carefully observed under polarizing microscope. Anatomical observations of thin sections revealed that this specimens belongs to family BETULACEAE *Alnoxylon sp. nov*. Diffuse Porous Alder wood is typically diffuse porous, meaning that the vessel elements are distributed relatively evenly throughout the growth rings. Vessels (Pores): Solitary Pores in a Frame-like Pattern: This could be characteristic of some hardwoods like alder, where solitary pores are present, and They could be positioned in a diagonal or roughly radial manner. Medium Pore Size: Alder wood often has medium-sized pores. Gum Deposits: Gum Deposit Present: Alder wood can have resinous substances or gum deposits. Perforation Plate: Simple Perforation Plate: The presence of a simple perforation plate is a feature found in some hardwoods, including Alder. Rays: Homogeneous Rays, Uniseriate Rays: Alder wood may exhibit homogeneous rays, and the uniseriate rays suggest that the rays are primarily composed of one cell type (Fig. 4.7, Fig. 4.8, and Fig. 4.9). The affinities with a section of the BETULACEAE genus *Alnus* are indicated by the presence of bending growth rings, numerous narrow and evenly distributed vessels, exclusively scalariform perforation plates, alternate to opposite intervessel pitting, homocellular uniseriate and aggregate rays, and diffuse-porous wood (Table: 4.8).

Table 4:8 Anatomical Observations of Specimen No. 89/Man/RK/11

Sr. No.	**Anatomical Features**	**Section** **r radial** **t tangential** **q transversal**	**Diagnostic Value** **h high** **me medium** **mo modest**	**Remarks**
	Vessels (Pores)			
1.	**Porosity of Vessels** **Ring porous**	**q**	**h**	----
2.	**Semi-ring porous:**	**q**	**me**	----
3.	**Diffuse porous:**	**q**	**h**	Present
	Grouping of Vessels			
4.	**Solitary pores:**	**q**	**me**	Present
5.	**Radial pore files:**	**q**	**h**	----
6.	**Pore cluster:**	**q**	**me**	----
	Orientation of Vessels			
7.	**Dendritic or flame like**	**q**	**h**	Present
8.	**Radial orientation**	**q**	**h**	----
9.	**Oblique orientation**	**q**	**h**	----
10.	**Tangential orientation**	**q**	**h**	----
Sizes of pores, Density of pores: The size and density of vessels (pores) in cross-section.				
11.	**Uniform distribution of pores.** **Large pores**	**q**	**h**	----
12.	**Medium-sized pores**	**q**	**me**	Present

13.	**Small pores**	**q**	**me**	----
14.	**Very small pores**	**q**	**h**	----
Tyloses: An outgrowth of an adjacent parenchyma cell through the pit cavity in a vessel wall. The vessel lumen may be obstructed.				
15.	**Gum deposits**	**q/r**	**me**	Present
16.	**Tyloses with thin walls.**	**q/r**	**h**	----
	Vessels and fibers in longitudinal section			
	Perforation plate:			
17.	**Simple perforation plate:**	**r**	**h**	Present
18.	**Scalariform perforation plate:**	**r**	**h**	----
19.	**Spiral thickenings:**	**r/t**	**h**	----
20.		**r/t**	**h**	----
21.		**r/t**	**mo**	----
22.	**Fiber- tracheids:**	**r**	**h**	----
23.	**Libriform fibres:**	**r**	**me**	----
24.	**Septate fibers:**	**r**	**me**	Present
	Rays in tangential section			
25.	**Homogeneous rays:**	**t**	**h**	Present
26.	**Heterogeneous rays:**	**t**	**h**	----
27.	**Uniseriate rays:**	**t**	**h**	Present
28.	**Biseriate to triseriate rays:**	**t**	**h**	----
29.	**Triseriate to 5-seriate rays:**	**t**	-----	
30.	**Storied rays:**	**t**	**me**	----
31.	**Uniseriate and multi-seriate rays:**	**t**	**h**	----
32.	**Aggregate rays:**	**t/q**	**h**	----
33.	**Sheath cells:**	**t**	**me**	----
34.		**q**	**h**	Present
Rays in radial section: The form of the ray cells is best represented in radial section.				
35.	**Homogeneous rays:**	**r**	**h**	Present
36.	**Heterogeneous rays, type I:**	**r**	**me**	----

37.	**Heterogeneous rays, type II:**	**r**	**h**	----
38.	**Heterogeneous rays, type III:**	**r**	**h**	----
39.		**r**	**h**	----
40.		**r**	**h**	----
41.		**r**	**h**	----
42.	**Development of a secondary ray:**	**r**	**me**	----
Parenchyma: Tissue composed of ± isodiametric cells and simple pits. Apotracheal parenchyma: Axial parenchyma not in direct contact with vessels.				
43.	**Diffuse, Apotracheal parenchyma:**	**q**	**Me**	Present
44.	**Banded, Apotracheal parenchyma:**	**q**	**h**	----
45.	**Paratracheal parenchyma:**	**q**	**h**	----
46.	**Traumatic parenchyma:**	**q**	**me**	----

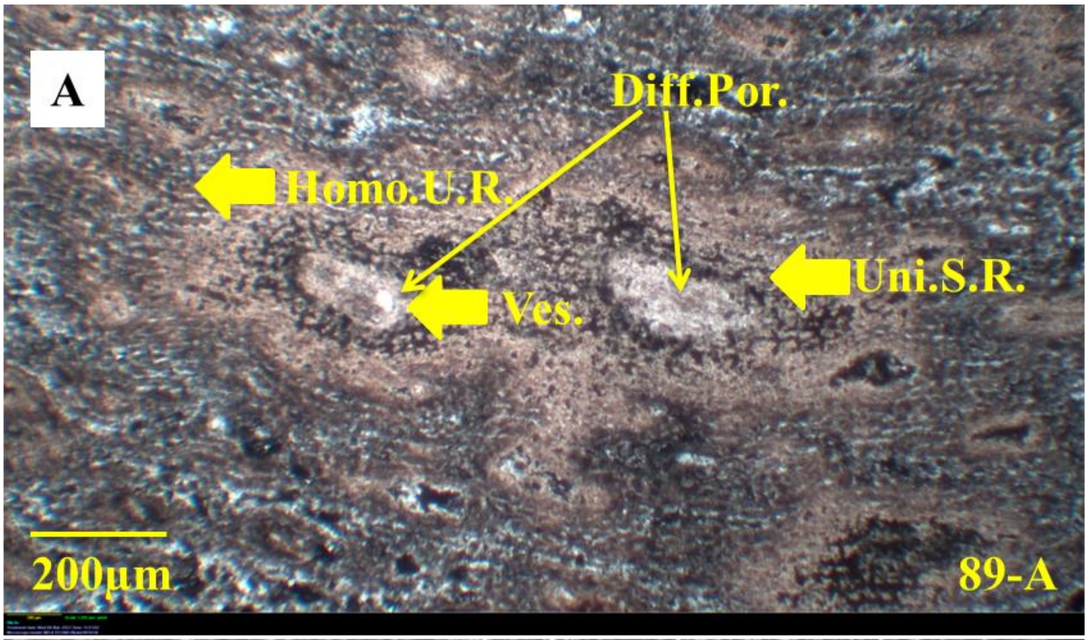
4.4.4. Affinities and comparison with fossils wood species

Thus far, six fossil woods from Tertiary layers around the world have been reported to resemble *Alnus*. These include *Alnus* sp. Slijper (1932) from the European Pliocene, *Alnus* sp. Hofmann (1944) from the Lower Oligocene of Europe, *Alnoxylon vasculosum* Felix emends. Müller-Stoll and Mädel (1959) from the German and Austrian Pliocene, *Alnoxylon* sp. Petrescu and Nutu (1969) from the Romanian Upper Miocene, *Alnuslatissima* Wheeler et al. (1977) from the American Eocene, and *Alnoxylon* sp. Gottwald (1981) identified species from the European Pliocene. *Alnus* sp. (Slijper, 1922) exhibits only uniseriate rays without any aggregate rays, alternating intervessel pitting, and diagonal and radial vessel multiples. There are aggregate rays in *Alnoxylon*sp. (Hofmann 1944), although the vessel's size and other information are not provided. Our fossil wood is similar to that of *Alnoxylon vasculosum* (Müller-Stoll and Mädel 1959) in terms of vessel size, frequency, number of bars per plate, and rays.

However, it is not the same since it does not include scalariform intervessel pitting. In contrast, *Alnoxylon sp*. (Petrescu and Nutu 1969) has uniseriate rays, entirely alternating intervessel pitting, and broader vessels (mean tangential diameter 100–200 µm).Although it lacks scalariform intervessel pitting, *Alnuslatissima* (Wheeler et al., 1977) resembles our fossil wood as well. The axial parenchyma was not documented. *Alnoxylon*sp. (Gottwald 1981) is characterized by solely uniseriate rays, diffuse-in-aggregate parenchyma in bands three cells wide and opposing intervessel pitting. **The Fossil wood is designated as *Alnoxylon* sp. nov.,** the specific epithet derived from its distinctive scalariform intervessel pitting, because it differs from all other previously reported fossils (Table: 4.8).

4.4.5. Comparison with modern wood species and affinities

Wood Taxonomists examined physical characteristics the extinct species is a member of the family BETULACEAE *Alnoxylon* sp. nov. and compared its characteristics with the modern species and reported many species of the Modern species belong to the family BETULACEAE *Alnoxylon sp. nov*. Following is the brief of some of the genus related to the Wood Fossil specimen (Table: 4.9);



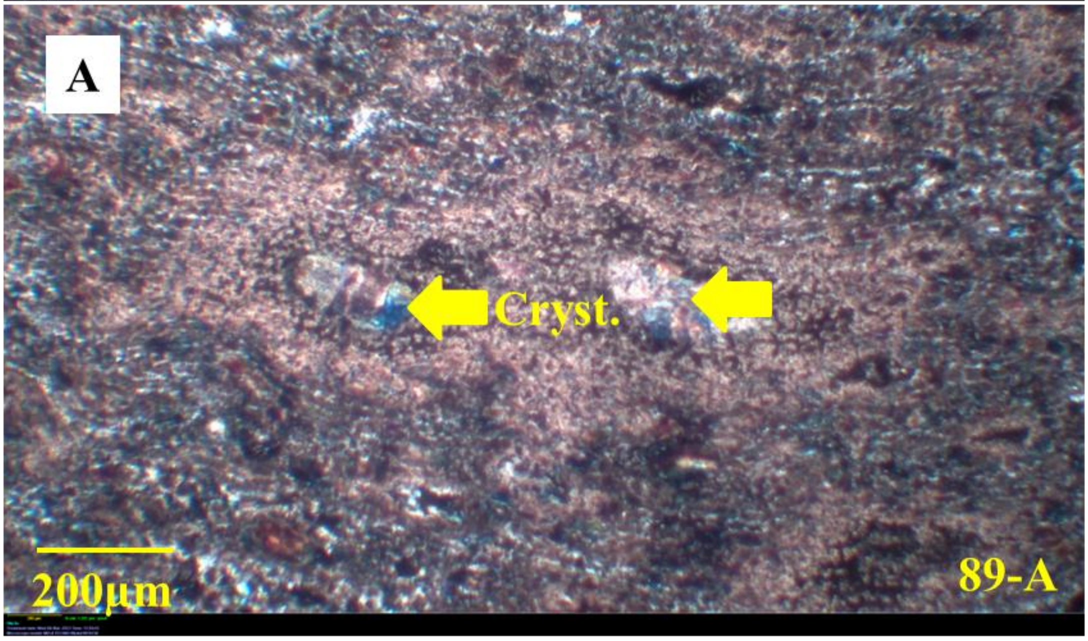


Figure 4.5 Transverse Thin Section of Specimen 89/Man/RK/11 showing distribution of pores and their nature A) Cross polarized light image B) Plan polarized light image;

A)	**Diff.Por.:**	**Diffuse Porous**
	Homo. U.R.:	**Homogeneous Uniseriate rays**
	Uni.R.:	**Uniseriate Rays**
	Ves.:	**Vessels**
B)	**Cryst.:**	**Crystals**

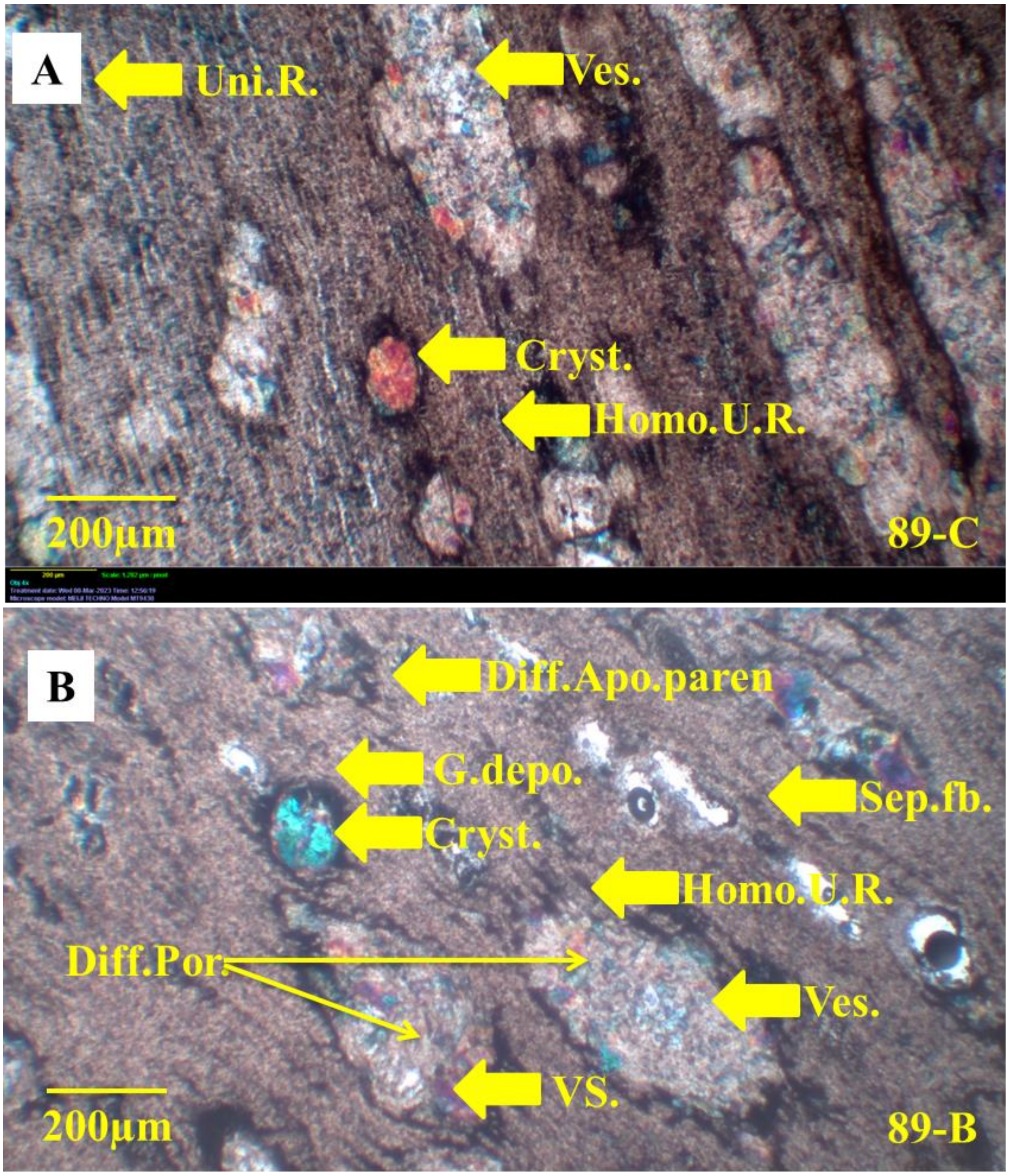


Figure 4.6 A) Tangential and B) Radial Thin Section of Specimen 89/Man/RK/11 showing arrangement of Vessels and Fibers in Cross polarized light image;

A)	**Ves.:**	**Vessels**
	Uni.R.:	**Uniseriate Rays**
	Cryst.:	**Crystals**
	Homo.U.R.:	**Homogeneous Uniseriate rays**
B)	**Diff. Apo.paren:**	**Diffuse, Apotracheal parenchyma**
	VS.:	**Vessels Solitary**
	Diff. Por.:	**Diffuse Porous**
	G.depo.:	**Gum deposits**

Table 4:9 On the basis of anatomical features of wood fossil specimen 89/Man/RK/11 the following wood fossil species reported in the world belong to the same genus

Sr. No.	Family Name	Genus	Region Habitat	Age	Geographical Distribution	Reference
1.	**BETULACEAE**	*Alnoxylonsp.*	Austria	Pliocene	Asia that is temperate and Europe Europe—apart from the Mediterranean	(Gottwald, 1981)
2.	**BETULACEAE**	*Alnoxylonsp.*	--	Miocene (Upper)	Asia that is temperate and Europe Europe—apart from the Mediterranean	(Petrescu and Nuţu, 1969)
3.	**BETULACEAE**	*Alnoxylon* sp.	East of Eielek Village - Gökçeada, Turkey Kesmekaya volcanics	Miocene (Lower)	Europe, mild Asia, the Mediterranean region (which includes Northern Africa), and the Middle East	(Güngör, Y.,et al, 2019)
4.	**BETULACEAE**	*Alnoxylonvasculosum* Felix emend. Müller-Stoll andMädel	--	Pliocene (Lower)	Asia that is temperate and Europe Europe—apart from the Mediterranean	(Müller-Stoll and Mädel, 1959)
5.	**BETULACEAE**	*Alnoxylonwillershausense*	--	Pliocene (Upper)	Asia that is temperate and Europe Europe—apart from the Mediterranean	(Müller-Stoll, 1954)

Table 4:10 On the basis of anatomical features of specimen 89/Man/RK/11 the following modern species reported in the world belong to the same genus

Sr. No.	Name of Family	Genus	Region Habitat	Age	Geographical Distribution	Reference
1.	**BETULACEAE**	*Alnusacuminata* Kunth (ANDEAN ALDER)	PROTA: introduced in Rwanda, Burundi, Kenya, Uganda and Madagascar Deciduous	Present	Mexico to northern Argentina 1,500 and 3,200 meters in mountain ranges	(del Rocío Barrera et al, 2018).
2.	**BETULACEAE**	*Alnus* sect. *Alnobetula* (ALDER) *Alnusalnobetulasub sp. alnobetula* (GREEN ALDER) *Alnusfirma Alnuspendula*Matsum. *Alnussieboldiana*Matsum.	BETULACEAE Alnus *Alnobetula* and *Alnuspendula* are deciduous	Present	Temperate Asia and Europe Russia, Japan, and China in temperate Asia North America, extending beyond Mexico	(Hall, J.W. 1952)
3.	**BETULACEAE**	*Alnuscremastogyne*	Cultivated in Jiangsu, Gansu, Sichuan, Guizhou, Shaanxi, and Zhejiang	Present	Temperate Asia and Europe Russia, Japan, and China in temperate Asia	**(Metcalfe, C.R., 1950)**

4.	**BETULACEAE**	*Alnusglutinosa* (L.) Gaertn. (EUROPEAN ALDER)	Tree shrub	Present	Temperate Asia and Europe Europe, with the exception of the Mediterranean, which includes the Middle East and Northern Africa	(Schweingruber, F. H., 1990)
5.	**BETULACEAE**	*Alnushirsuta* (Spach) Rupr. (ALDER)	China: Temperate forests, along stream banks; 700-1500 m. China: Heilongjiang, Jilin, Liaoning, Nei Mongol, Shandong [Japan, Korea, Russia (Siberia)]	Present	Temperate Asia and Europe Russia, Japan, and China in temperate Asia	Eom, Y. G. (2015)

4.4.6. PALEOCLIMATOLOGY

In Gökçeada, a newly found fossil woodland site along the coast that covers an area of roughly 1.5 square kilometers, (Güngör et al., 2019) gathered 16 wood fossil specimens from the upper slope and sea shore. In order to reconstruct the paleo-climate, his study aimed to describe paleo-ecology and paleo-biology. He performed anatomical studies on these speciemens and three conifers were found (*Cupressinoxylon, Sequoioxylon*, and *Pinoxylon*) and nine angiosperms (*Alnoxylon, Carpinoxylon, Ostryoxylon, Palmoxylon* types 1 and 2, *Fagoxylon, Quercoxylon* sect. *Ilex, Laurinoxylon*, and *Platanoxylon*) made up the total of 12 altogether. The wood composition of Gökçeada is similar to the Miocene wood flora of Lesvos, showing the presence of riparian, well-drained lowland and coastal species.

(Srivastava and Suzuki, 2001) collected five species from Tsuyazaki Formation Oligocene age, Tsuyazaki, Fukuoka Prefecture, Northern Kyushu, Japan. Authors described five species of *Rhuspalaeojavanica* (Anacardiaceae), *Alnusscalariforme* (Betulaceae), *Hamamelisprejaponica* (Hamamelidaceae), *Magnoliaceoxylon palaeogenica* (Magnoliaceae) and *Sonneratiakyushuensis* (Sonneratiaceae).Before this research, 14 species were discovered from the area of Tsuyazaki. With the exception of *Sonneratia*, which is located in the current mangrove vegetation of tropical to subtropical forests, they discovered that the Nearest Living Relatives (NLRs) of these species are found in temperate to subtropical forest regions. *Sonneratia* could suggest that early Oligocene temperatures in Kyushu were higher.

Presently, genus of 35 species of *Alnus* (Alder) is spread in the temperate Asia, China, Japan, Europe, Mexico, North America and in Argentina on 1,500 and 3,200 meters in mountain ranges(Silvester, 1977). In Pakistan, *Alnus* (Alder) are found in the region of Swat, Dir, Gilgit and lower mountain sides. According to (Beck et al., 2018), climate of most of regions of Pakistan including Sindh is Arid, desert, hot (BWh) as per Köppen-Geiger climate classification map for Pakistan (1980-2016). While some parts of Balochistan, Southern Punjab, Northern Punjab, Khyber Pakhtunkhwa, Gilgit-Baltistan consist on arid steppe and Temperate to cold regions. Presence of BETULACEAE *Alnoxylon*sp.nov.in the area of Ranikot, Sindh indicate that this region had temperate climate during Miocene and Pliocene where these species were found.

4.5. SAPINDACEAE *Aceroxylon* (New Specie)

4.5.1. Holotype

The sample is collected during field work from Manchar Formation of Miocene age, in the area of Ranikot, District Jamshoro, Sind Pakistan. The specimen is labeled as "95/Man/RK/11".

4.5.2. Morphological description of specimen

Selected specimen No. 95/Man/RK/11 is one piece of fairly well preserved silicified wood fossil. It seems to be a piece of stem. It is 13cm in height and probably same height on the other side. Length is 26 cm. 6cm piece from length is marked to be cut for pulverization (Fig. 3.6). Fossil is yellowish brown in colour. On bottom and top of the specimen grayish colour is visible.

4.5.3. Anatomical description of specimen

Anatomical characteristics of specimen 95/Man/RK/11 observed under Polarized microscope and study of Transverse, Radial and Tangential thin sections revealed that growth ring are present mark by 2-4 terminal rows of fibers, wood diffuse porous wood mostly solitary porous 2-5 pores, vessel, the vessels have simple perforation bordered pits alternate, the axial parenchyma is apotracheal type, as few short tangential uniseriate chains, or radial, in the terminal wood bands of 2-3 cells thick, and diffuse also. Parenchyma cells appear also of paratracheal type is vascientric medullary rays are uniseriate to bi-seriate and the remaining all detailed characters refer to this fossil wood belongs to Sapindaceae family (Fig. 4.10, Fig. 4.11, and Fig. 4.12) (Table: 4.11).

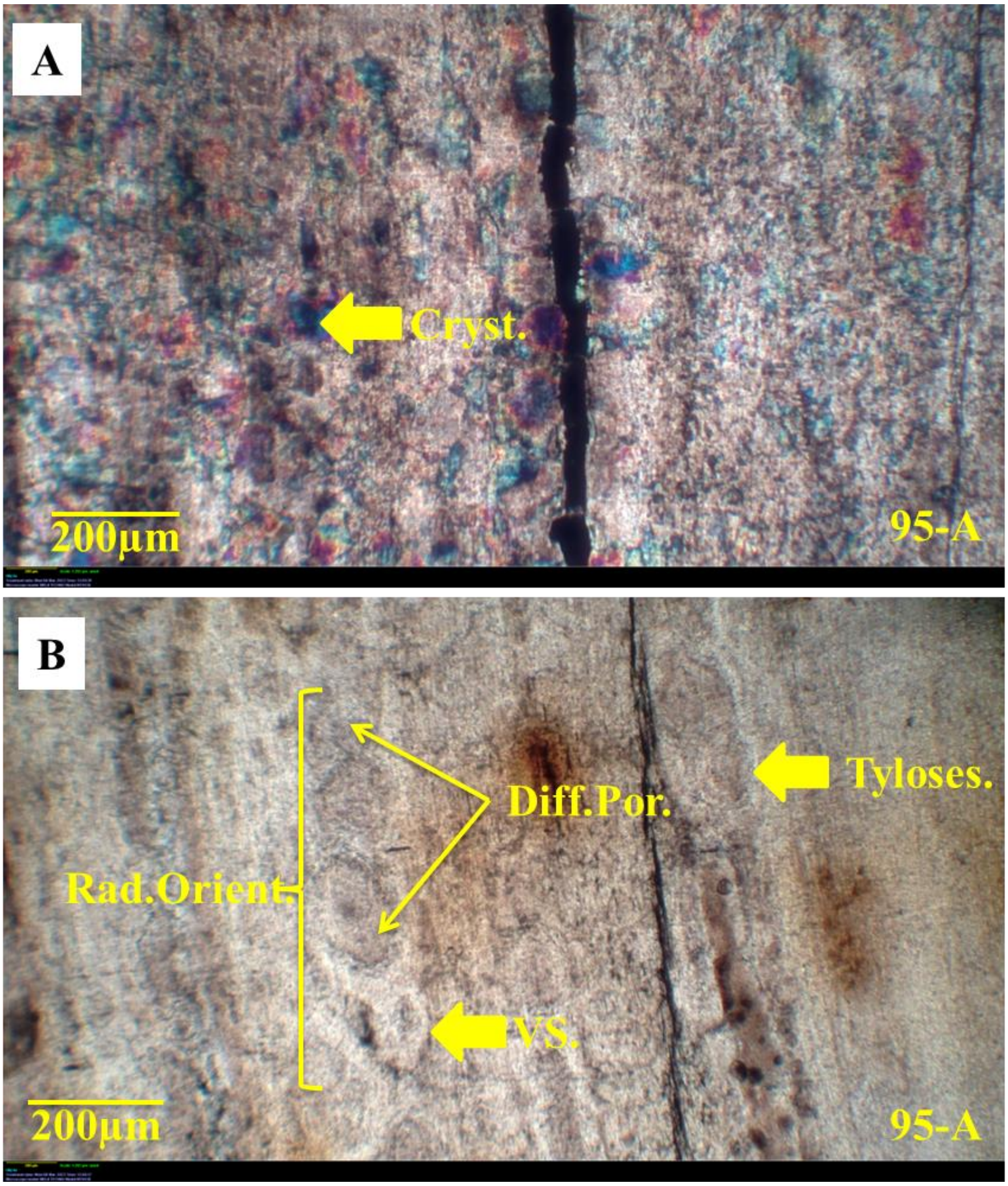


Figure 4.7 Transverse Thin Section of Specimen 95/Man/RK/11 showing distribution of pores and their nature A) Cross polarized light image B) Plan polarized light image:

A)	**Cryst.:**	**Crystals**
B)	**VS.:**	**Vessels Solitary**
	Rad.Orient.:	**Radial orientation**
	Diff.Por.":	**Diffuse Porous**

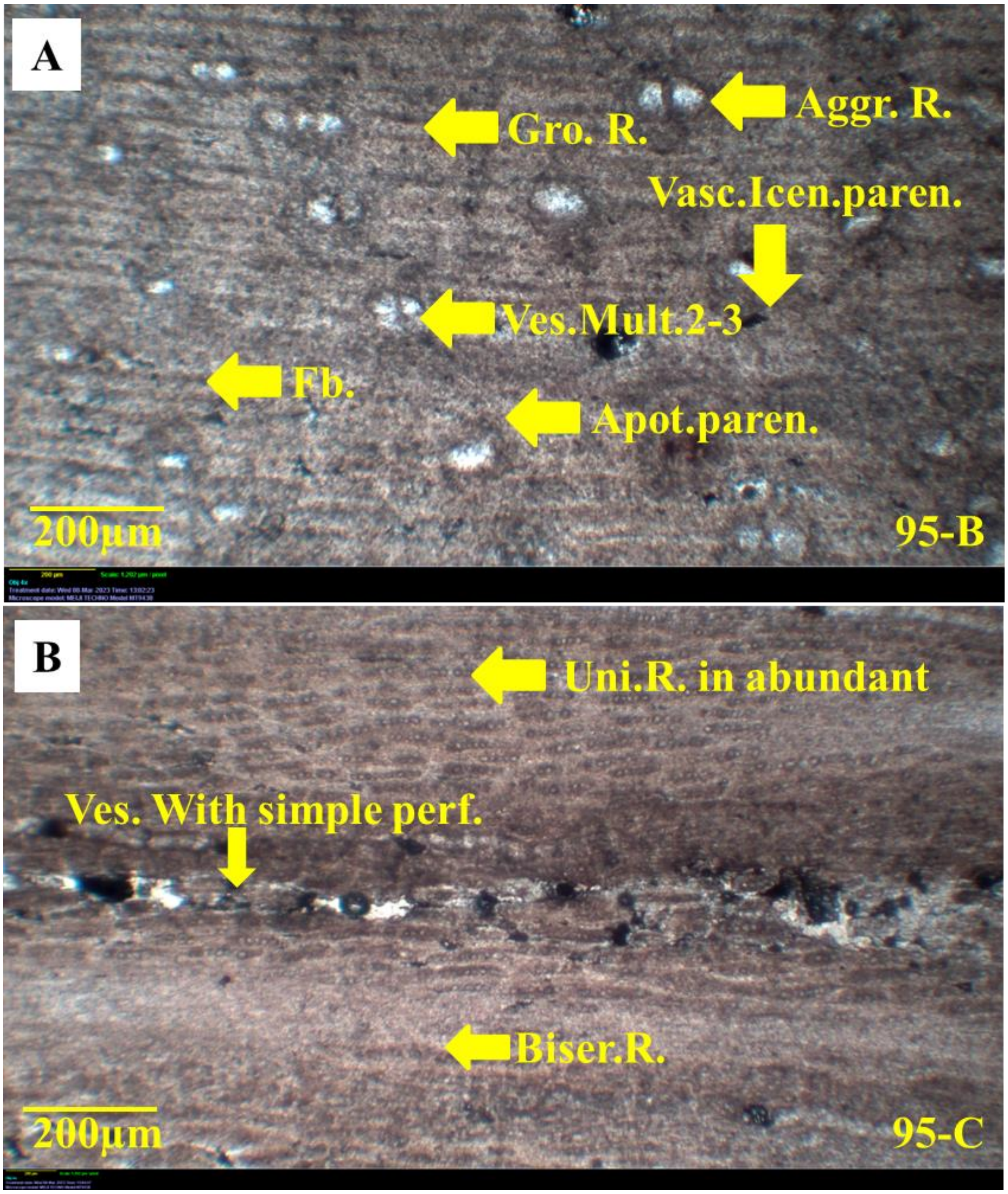


Figure 4.8 A) Radial and B) Tangential Thin Sections of Specimen 95/Man/RK/11 showing arrangement of Vessels and Fibers in Plan polarized light image:

A)	**Aggr.R.:**	**Aggregate rays**
	Gro.R.:	**Growth Rings**
	Vasc.Icen.paren.:	**Vascular Icentric parenchyma**
	Ves. Mult.2-3:	**Vessels multiple of 2-3**
	Fb.:	**Fibers**
	Apot.paren.:	**Apotracheal parenchyma**
B)	**Uni.R. in abundant:**	**Uniseriate in abundant**
	Ves. With simple perf.:	**Simple perforation plate:**
	Biser.R.:	**Biseriate Rays**

Table 4:11 Anatomical Observations of Specimen No. 95/Man/RK/

Sr. No.	Anatomical Features	Section r radial t tangential q transversal	Diagnostic Value h high me medium mo modest	Remarks
	Vessels (Pores)			
1.	**Porosity of Vessels Ring porous**	**q**	**h**	----
2.	**Semi-ring porous:**	**q**	**me**	----
3.	**Diffuse porous:**	**q**	**h**	Present
4.	**Solitary pores:**	**q**	**me**	Present
5.	**Radial pore files:**	**q**	**h**	----
6.	**Pore cluster:**	**q**	**me**	----
7.	**Dendritic or flame like**	**q**	**h**	----
8.	**Radial orientation**	**q**	**h**	Present
9.	**Oblique orientation**	**q**	**h**	----
10.	**Tangential orientation**	**q**	**h**	----
Sizes of pores, Density of pores: The size and density of vessels (pores) in cross-section.				
11.	**Uniform distribution of pores. Large pores**	**q**	**h**	----
12.	**Medium-sized pores**	**q**	**me**	----
13.	**Small pores**	**q**	**me**	Present
14.	**Very small pores**	**q**	**h**	----
Tyloses: An outgrowth of an adjacent parenchyma cell through the pit cavity in a vessel wall. The vessel lumen may be obstructed.				
15.	**Gum deposits**	**q/r**	**me**	----
16.	**Tyloses with thin walls.**	**q/r**	**h**	Present
	Vessels and fibers in longitudinal section			
	Perforation plate:			
17.	**Simple perforation plate:**	**r**	**h**	Present

18.	**Scalariform perforation plate:**	**r**	**h**	Present
19.	**Spiral thickenings:**	**r/t**	**h**	----
20.		**r/t**	**h**	----
21.		**r/t**	**mo**	----
22.	**Fiber- tracheids:**	**r**	**h**	----
23.	**Libriform fibers:**	**r**	**me**	----
24.	**Septate fibers:**	**r**	**me**	Present
Rays in tangential section				
25.	**Homogeneous rays:**	**t**	**h**	Present
26.	**Heterogeneous rays:**	**t**	**h**	----
27.	**Uniseriate rays:**	**t**	**h**	Present
28.	**Biseriate to triseriate rays:**	**t**	**h**	----
29.	**Triseriate to 5-seriate rays:**	**t**	**-----**	----
30.	**Storied rays:**	**t**	**me**	----
31.	**Uniseriate and multi-seriate rays:**	**t**	**h**	----
32.	**Aggregate rays:**	**t/q**	**h**	Present
33.	**Sheath cells:**	**t**	**me**	----
34.		**q**	**H**	----
Rays in radial section: The form of the ray cells is best represented in radial section.				
35.	**Homogeneous rays:**	**r**	**h**	Present
36.	**Heterogeneous rays, type I:**	**r**	**me**	----
37.	**Heterogeneous rays, type II:**	**r**	**h**	----
38.	**Heterogeneous rays, type III:**	**r**	**h**	----
39.		**r**	**h**	Present
40.		**r**	**h**	----
41.		**r**	**h**	----
42.	**Development of a secondary ray:**	**r**	**me**	----
Parenchyma: Tissue composed of ± isodiametric cells and simple pits. **Apotracheal parenchyma:**				

Axial parenchyma not in direct contact with vessels.				
43.	**Diffuse, Apotracheal parenchyma:**	**q**	**Me**	Present
44.	**Banded, Apotracheal parenchyma:**	**q**	**H**	
45.	**Paratracheal parenchyma:**	**q**	**H**	Present
46.	**Traumatic parenchyma:**	**q**	**Me**	----

4.5.4. Affinities and comparison with fossils wood species

Wood anatomists all around the world carried out research on the anatomical features of petrified wood specimens for the identification of species and to reconstruct the pre-historic environment by comparing anatomical features of these species to their Nearest Living Relatives (NRLs). Comparing the xylotomic properties found in the specimens under investigation, it was possible to observe strong overlaps with the characters of the ancient Aceraceae family, especially those of the *Acer* type, as documented by Hofmann (1952). This genus is currently a member of the Sapindaceae family (Table: 4.11).

The general anatomical traits of Acer's secondary wood structure: Diffuse-porous wood with distinct growth rings identified by a few rows of flattened fibers; pores single, spaced, or in short multiples; spiral thickenings vertically; alternating pitting; simple perforations; and scanty apotracheal parenchyma diffuse, semi-paratracheal, infrequently terminal; rays slightly dilated to the ring boundary; radially homocellular appearance; marginal cells square and with wide pitting (Schweingruber, 1990; Watson and Dalwitz, 1992)."

According to Te-rada (1998) and Wheeler and Manchester (2002), there are at least eighteen species of fossilized *Acer* wood known to exist in North America, Madagascar, Europe, Japan, and a few other places. They are divided into two categories: those with wide ray (1-3 cells wide) and those with narrow rays (1-3 cells wide). Our *Acer* fossils can be identified as *Aceroxylon* due to their thin rays. Following are the various species identified in the other parts of the world (Table: 4.12);

Acer beckianum Prakash and Barghoorn, *Acer cf. amoenum* Watari, *Acer cf. amoenum* Watari, *Acer integrifolioxylon* Wheeler and Manchester, *Acer minokamoensis*, *Acer olearyi* Prakash and Barghoorn, *Acer palmatoxylum* Suzuki, *Acer puratanum* Prakash and Barghoorn, *Acer watarianum* Takahashi and Suzuki are the fossil wood described from the different regions of world.

Table 4:12 On the basis of anatomical features of specimen No. 95/Man/RK/11 the following wood fossil species reported in the world belongs to the same genus

Sr. No.	Name of Family	Genus	Region Habitat	Age	Geographical Distribution	Reference
1.	**SAPINDACEAE**	*Acer beckianum* Prakash and Barghoorn	Vantage, WA, USA	Miocene (Middle)	North America, north of Mexico	(Prakash and Barghoorn, 1961) (Wheeler and Dillhoff, 2009)
2.	**SAPINDACEAE**	*Acer berkhoffii* Wheeler and Dillhoff	Vantage, WA, USA	Miocene (Middle)	North America, north of Mexico	(Prakash, 1968) (Wheeler and Dillhoff, 2009)

3.	**SAPINDACEAE**	*Acer cf. amoenum* Watari	Honshu, Japan	Miocene	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(WATARI, 1952)
4.	**SAPINDACEAE**	*Acer integrifolioxylon* Wheeler and Manchester	Oregon, USA	Eocene (Middle)	North America, north of Mexico	(Wheeler and Manchester, 2007)
5.	**SAPINDACEAE**	*Acer minokamoensis*	Shinjeong-ri, Donghae-myeon, Pohang City, Korea	Miocene (Lower)	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Jeong et al., 2009)
6.	**SAPINDACEAE**	*Acer momijiyamense* Takahashi and Suzuki	--	Oligocene	Europe and temperate Asia	(Takahashi and Suzuki, 1988)
7.	**SAPINDACEAE**	*Acer olearyi* Prakash and Barghoorn	Vantage, WA, USA	Miocene (Middle)	North America, north of Mexico	(Prakash and Barghoorn, 1961)

8.	**SAPINDACEAE**	*Acer palmatoxylum* Suzuki	N Kyushu, Japan	Oligocene	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Suzuki, 1982)
9.	**SAPINDACEAE**	*Acer pohangensis*	Korea's Shinjeong-ri in Donghae-myeon and Pohang City	Miocene (Lower)	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Jeong et al., 2009)

4.5.5. Comparison with modern wood species and affinities

Wood Taxonomists examined physical characteristics The extinct species is a member of the family SAPINDACEAE *Aceroxylon* sp. nov. and compared its characteristics with the modern species and reported many species of the Modern species belong to the family SAPINDACEAE *Aceroxylon* sp. nov. Following is the brief of some of the genus related to the Wood Fossil specimen (Table: 4.13);

Table 4:13 On the basis of anatomical features of specimen 95/Man/RK/11 the following modern species reported in the world belong to the same genus

Sr. No.	Name of Family	Genus	Region Habitat	Age	Geographical Distribution	Reference
1.	**SAPINDACEAE**	*Acer amoenum* Carr.	Temperate Asia (China), Japan, Russia Deciduous	Present	Europe and temperate Asia	(Sudo, 2007)
2.	**SAPINDACEAE**	*Acer argutum* Maxim. (POINTED-LEAF MAPLE)	cool temperate to lower subalpine forests, usually moist sites at stream sides at elevations of 800 - 1900 m Deciduous	Present	Europe and temperate Asia	(Sudo, 2007)

3.	**SAPINDACEAE**	*Acer campbellii* Hook.f. et Thoms	Himalayas, Bhutan, N India, Myanmar, Nepal, Vietnam, China (Yunnan, Sichuan, Xiang) Deciduous, upper temperate zone (Himalayas), mixed forests	Present	Asia that is temperate and Europe Russia, Japan, and China in temperate Asia Central Asia **Pakistan**, India, and Sri Lanka Myanmar Asia-Pacific and Southeast Asia Vietnam, Cambodia, Laos, Thailand (Indochina)	(Suzuki, 1991)
4.	**SAPINDACEAE**	*Acer campestre* L. (FIELD MAPLE, HEDGE MAPLE)	--	Present	Europe and temperate Asia Europe, excluding Mediterranean	(Grosser, 1977) (Schweingruber, 1990)

5.	**SAPINDACEAE**	*Acer capillipes* Maxim. (JAPANESE STRIPED-BARK MAPLE, RED-BUDDED SNAKE BARK)	Japan cultivated ornamental Deciduous	Present	Asia that is temperate and Europe Russia, Japan, and China in temperate Asia	(Sudo, 2007)

4.5.6. Paleoclimatology

E.A. Wheeler and T.A. Dillhoff conducted research on Miocene age petrified wood fossil specimens from Vantage Forest preserved at Ginkgo Petrified Forest State Park, Washington, USA and reconstructed the paleo-climate of the area. They discovered 34 angiosperms and 6 gymnosperms diverse species of Miocene age from this single location. Wheeler and Dillhoff discovered species of *Piceoxylon*, *Ulmus*, *Juglandaceous*, *Liquidambar*, *Acer*, *Quercus*, *Locust* and *Gordonia* (= *Hamamelis*). They compared anatomical features of these species and with their modern times relatives species. On the basis of relationship they established these wood fossils species with their present living species, (Wheeler and Dillhoff, 2009) concluded that in the Middle Miocene time climate was significant throughout different from the todays' environment. At Vantage, the current climate is defined by chilly winters, dry, scorching summers, and fewer than 20 centimeters of yearly precipitation. The rain shadow cast by the north-south running Cascade mountain range, which absorbs a large portion of the moisture entering from the Pacific Ocean, is the reason for the low level of precipitation. There was less latitudinal temperature gradient and higher average global temperatures throughout the Middle Miocene (Wolfe, 1978). The Cascade Mountain range had not ascended high enough to provide a rain shadow during the Middle Miocene (Reiners et al. 2002). As indicated by the affinity of the Vantage assemblage with the contemporary forests of eastern Asia and eastern North America, there was copious rainfall during the growing season. The Miocene saw the creation of forests that were very different from the current dry summer climatic forests of the Pacific Northwest due to a combination of greater regional temperatures and sufficient summer rainfall.

Jeong gathered 38 exceptionally well-preserved wood fossils from the Janggi Group's Lower Coal-bearing Formation (Jeong et al., 2009) in Donghae-myeon, Pohang City, Gyeongsangbuk-do, Prefecture, Korae. Of these, 14 species were recognized, representing eleven genera and seven families. He found seven new genera and identified the genus of *Carya koreana* Jeong et Kim, *Betula janggiensis* Jeong et Kim, *Carpinus donghaensis* Jeong et Kim, *Ostrya geumgwangensis* Jeong et Kim, *Stewartia pseudo-camellioxylon* Jeong et Kim, *Acer minokamoensis* Jeong, Kim et Suzuki and *Acer pohangensis* Jeong et Kim. Based on these species, (Jeong et al., 2009) found a relationship between wood fossil species and living species and calculated the temperature shift of the Pohang Basin from cool-temperate to warm-temperate and subtropical during the Miocene.

In the present time, family SAPINDACEAE genus *Acer* various species are found in the temperate Asia (China), Southeast Asia, Russia, India, **Pakistan**, Sri Lanka, Burma, Thailand Vietnam and Cambodia. Modern hard wood *Acerargutum* Maxim (POINTED-LEAF MAPLE) is found at cool temperate to lower subalpine forests, usually moist sites at stream sides at elevations of 800 - 1900 m. These living species of *Acer* are deciduous in nature. There is a lot of moisture in deciduous woodlands. Broad-leaved leaves are typically found in the understory, shrub, and ground layers of the canopy. The primary characteristics of deciduous forests include South Pine and Oak, Central Hardwood, and Northern Hardwood. There are roughly 120 species in the genus Acer; 8 of those are found in Pakistan, and 2 of those are cultivated (Flora of Pakistan). Family SAPINDACEAE genus, *Acer acuminatum* Wall. ex D. Don is reported in the areas of Keran, Neelam valley in Kashmir by R.R. Stewart, l.c.

In contrast with the other regions of the world, Pakistan had very diverse climate during in Miocene period. As we could see that species of *Acer* re found in the regions of Himalaya, India, Nepal, Myanmar, Bhutan and mountain regions specifically in Pakistan, which has lower subalpine to cold temperate forests, typically damp locations along stream banks at elevations between 800 to 1900 meters. (Soomro et al., 2021), collected wood fossils specimens from the Ranikot area and carefully examined the anatomical characteristics of these petrified wood fossils. On the basis of anatomical features, (Soomro et al., 2021) identified six species of single genera Ispberlinia Craib and Stapf which are all found in the tropical Africa and from the previously documented species suggest that the Ranikot region clearly has a tropical climate. A tropical climate is one that is typical of the tropics. In this humid climate, the mean temperature is higher than 18°C (64.4 °F) for all twelve months. In some tropical climates, rainfall is a year-round occurrence, primarily during the afternoon. Others, like those affected by the monsoon, have a wet and a dry season. The typical tropical weather is hot, muggy, and humid. In a tropical climate, cold weather phenomena like frost and cold weather precipitation like snow are nonexistent. The Amazon rainforest, known for its rich biodiversity, is one well-known region with a tropical climate. Recent time area of Sindh is classified as Arid, hot and deserted climate. Report of SAPINDACEAE *Acer* from the Ranikot (as a New Specie) is the clear evidence that in the prehistoric time Ranikot and other areas were the habitat of SAPINDACEAE Acer and had favorable environment was supported in its growth.

4.6. FAGACEAE Castanopsis ranikotensis

4.6.1. Holotype

The sample is collected during field work from Manchar Formation of Miocene age, in the area of Ranikot, District Jamshoro, Sind Pakistan. The specimen is labeled as "108/Man/RK/11".

4.6.2. Morphological description of specimen

Selected specimen No. 108/Man/RK/11 is one piece of fairly well preserved silicified wood fossil. It may be the piece of part of the stem. It is 11.9cm in height and 22 cm in length. Fossil is light brown in colour from the front and light yellowish brown in colour from backside. 5.5cm piece from length is marked to be cut for pulverization (Fig. 3.5).

4.6.3. Anatomical description of specimen

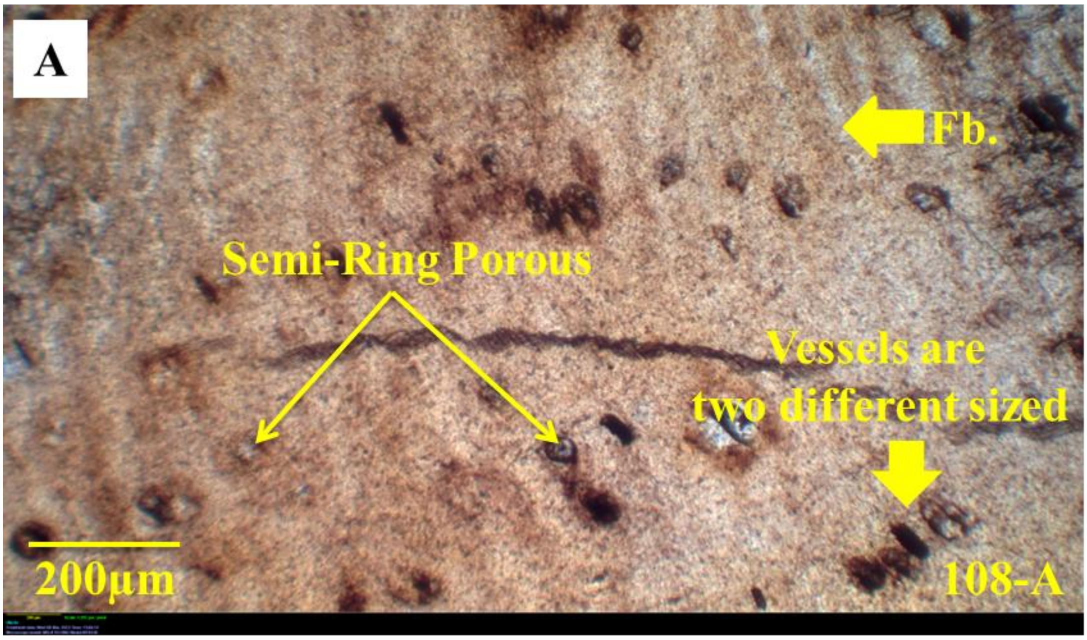
Three types of Thin Section 1) Transverse B) Radial and C) Tangential cross sections were examined under the polarized microscope and on the basis of anatomical features it is observed that on the base of these characteristics, the family FAGACEAE is a good contender (Fig. 4.13, Fig. 4.14 and Fig. 4.15). The following summarizes the ways in which the traits and the FAGACEAE family correspond: Semi-Ring Porous Wood: FAGACEAE, including oaks and chestnuts, often exhibit semi-ring porous wood. Solitary and Multiple of 2: Some species in the FAGACEAE family can have solitary or paired (multiple of 2) arrangement of pores Small Pores: FAGACEAE typically has small pores. Dendritic Flame-Like Arrangement: While dendritic structures can be observed in various families, including FAGACEAE, it's not a unique feature to this family. Scalariform Perforation: FAGACEAE may exhibit Scalariform perforation plates in their vessels. Septate Fibre: Presence of septate fibres is a characteristic feature in some species of FAGACEAE. Heterogeneous Rays and 1-4 Seriate Rays: Fagaceae is known for having heterogeneous rays, and these rays can be 1-4 Seriate. Vascicentric Parenchyma: The presence of vasicentric parenchyma is consistent with some features observed in Fagaceae (Table: 4.14).

Table 4:14 Anatomical Observations of Specimen No. 108/Man/RK/11

Sr. No.	Anatomical Features	Section r radial t tangential q transversal	Diagnostic Value h high me medium mo modest	Remarks
Vessels (Pores)				
1.	**Porosity of Vessels** **Ring porous**	**q**	**h**	----
2.	**Semi-ring porous:**	**q**	**me**	Present
3.	**Diffuse porous:**	**q**	**h**	----
Grouping of Vessels				
4.	**Solitary pores:**	**q**	**me**	Present
5.	**Radial pore files:**	**q**	**h**	----
6.	**Pore cluster:**	**q**	**me**	----
Orientation of Vessels				
7.	**Dendritic or flame like**	**q**	**h**	Present
8.	**Radial orientation**	**q**	**h**	----
9.	**Oblique orientation**	**q**	**h**	----
10.	**Tangential orientation**	**q**	**h**	----
Sizes of pores, Density of pores: The size and density of vessels (pores) in cross-section.				
11.	**Uniform distribution of pores.** **Large pores**	**q**	**h**	----
12.	**Medium-sized pores**	**q**	**me**	Present
13.	**Small pores**	**q**	**me**	----

14.	**Very small pores**	**q**	**h**	----
Tyloses: An outgrowth of an adjacent parenchyma cell through the pit cavity in a vessel wall. The vessel lumen may be obstructed.				
15.	**Gum deposits**	**q/r**	**me**	Present
16.	**Tyloses with thin walls.**	**q/r**	**h**	----
Vessels and fibers in longitudinal section				
Perforation plate:				
17.	**Simple perforation plate:**	**r**	**h**	Present
18.	**Scalariform perforation plate:**	**r**	**h**	Present
19.	**Spiral thickenings:**	**r/t**	**h**	----
20.		**r/t**	**h**	----
21.		**r/t**	**mo**	----
22.	**Fiber- tracheids:**	**r**	**h**	----
23.	**Libriform fibres:**	**r**	**me**	----
24.	**Septate fibers:**	**r**	**me**	Present
Rays in tangential section				
25.	**Homogeneous rays:**	**t**	**h**	Present
26.	**Heterogeneous rays:**	**t**	**h**	Present
27.	**Uniseriate rays:**	**t**	**h**	Present
28.	**Biseriate to triseriate rays:**	**t**	**h**	Present
29.	**Triseriate to 5-seriate rays:**	**t**	**-----**	----
30.	**Storied rays:**	**t**	**me**	----
31.	**Uniseriate and multi-seriate rays:**	**t**	**h**	----
32.	**Aggregate rays:**	**t/q**	**h**	----
33.	**Sheath cells:**	**t**	**me**	----
34.		**q**	**h**	
Rays in radial section: The form of the ray cells is best represented in radial section.				
35.	**Homogeneous rays:**	**r**	**me**	
36.	**Heterogeneous rays, type I:**	**r**	**h**	Present
37.	**Heterogeneous rays, type II:**	**r**	**h**	----
38.	**Heterogeneous rays, type III:**	**r**	**h**	----
39.		**r**	**h**	----

40.		**r**	**h**	----
41.		**r**	**h**	----
42.	**Development of a secondary ray:**	**r**	**me**	Present
Parenchyma: Tissue composed of ± isodiametric cells and simple pits. **Apotracheal parenchyma:** **Axial parenchyma not in direct contact with vessels.**				
43.	**Diffuse, Apotracheal parenchyma:**	**q**	**me**	----
44.	**Banded, Apotracheal parenchyma:**	**q**	**h**	----
45.	**Paratracheal parenchyma:**	**q**	**h**	Present
46.	**Traumatic parenchyma:**	**q**	**me**	----



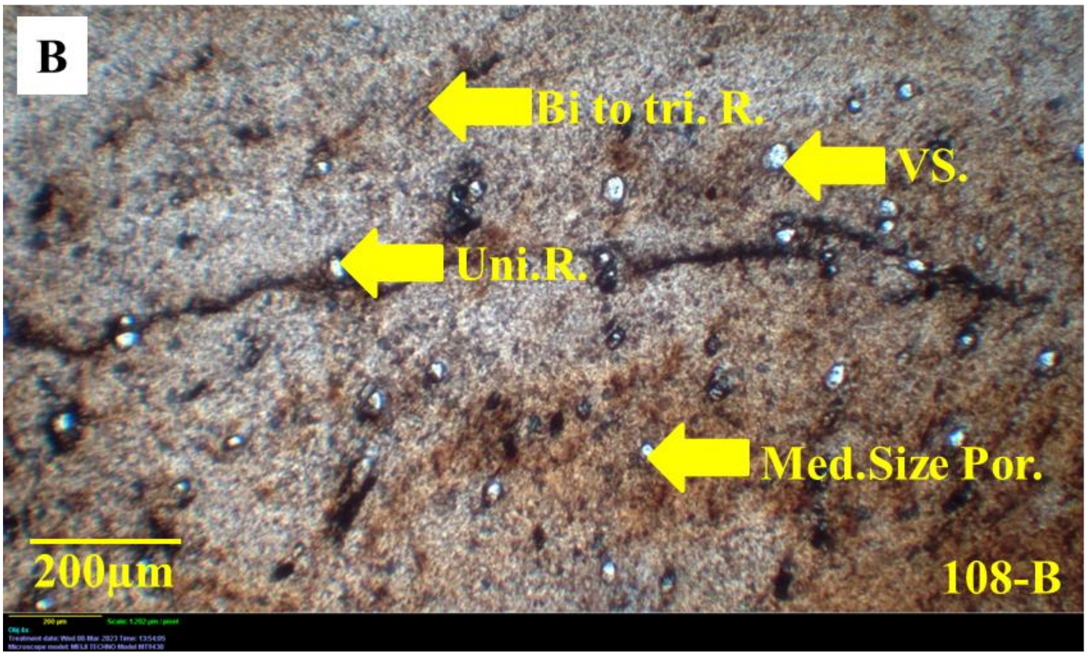


Figure 4.9 A) Transverse and B) Radial Thin Sections of Specimen 108/Man/RK/11 showing distribution of pores and their nature:

A)	**Fb.:**	**Fibers**
B)	**Bi to tri. R.:**	**Biseriate to triseriate rays**
	VS.:	**Vessels Solitary**
	Uni.R.:	**Uniseriate Rays**
	Med.Size Por.:	**Medium Size Pores**

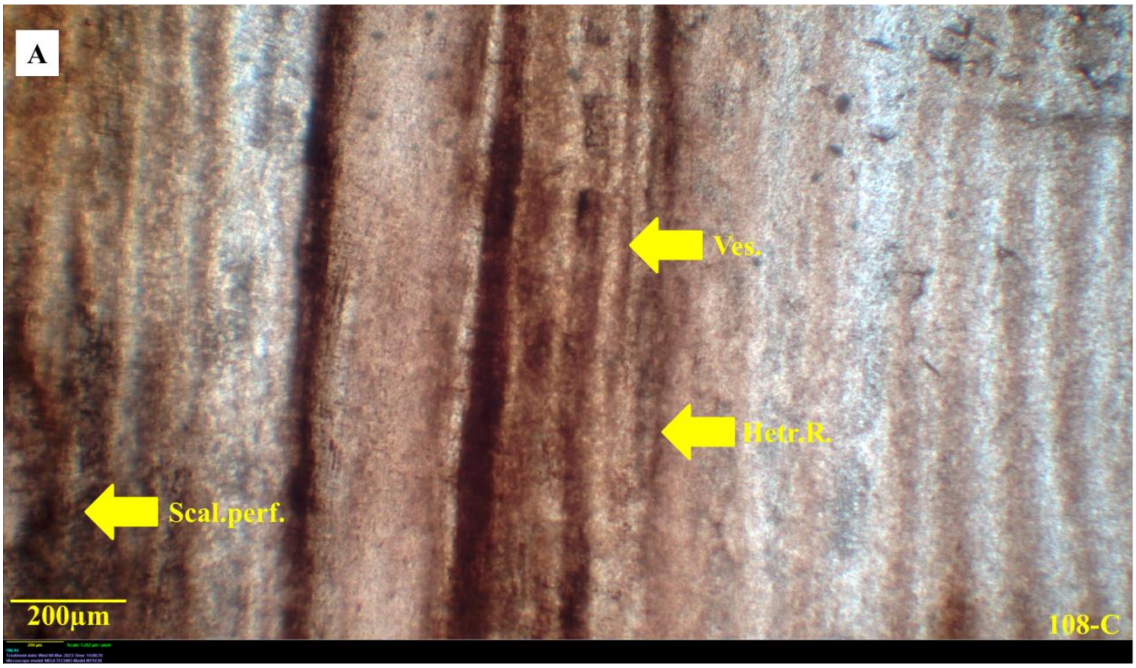


Figure 4.10 Tangential Thin Section of Specimen 108/Man/RK/11 showing arrangement of Vessels and Fibers in Plan polarized light image:

A)	**Ves.:**	**Vessels**
	Hetr.R.:	**Heterogeneous rays**
	Scal.perf.:	**Scalriform perforation**

4.6.4. Affinities and comparison with fossils wood of FAGACEAE

The sample appears to be from an evergreen oak tree based on the progressive (semi-ring/diffuse) porosity of the vessels, the presence of two different types of rays (uniseriate and multiseriate aggregate), and the oval shape of the single vessel outline. Different species of *Lithocarpoxylon*, *Quercoxylon* and *Castanopsis* represent the fossil "evergreen oaks.

Fossil wood shows some similarities with *Lithocarpoxylon*, *Lithocarpoxylon* is a genus with "growth rings distinct or scarcely distinct," according to Petrescu (1978). Wood with scattered or radial pores. Vessels only one, round to oval, gradually or vaguely transition from early to late wood. Perforation plates are only simple. However, Scalriform as well as simple perforation has been observed from the fossil under investigation. There is parenchyma and a vasicentric tracheid. Fibers are abundant. There are two different kinds of rays: a) broad, heterocellular, aggregate, and b) thin, 1-seriate, highly many, homocellular rays. Similarly, fossil wood under investigation has heterocellular rays as well as homocellular rays. In addition to describing the cellular makeup of the rays, Petrescu (1978) pointed out that the primary distinction between *Quercoxylon* and *Lithocarpoxylon* is the latter's sole presence of heterocellular aggregation rays.

According to their porosity, Selmeier (1992b) classified *Quercoxylon* types from Southern Germany into three groups: (a) evergreens (diffuse-porous woods) dating from the Late Pliocene, (b) ring-porous white oaks from the Late Miocene, and (c) red oaks (semi-ring porous). Selmeier noted that whilst white oaks have heterocellular rays and red oaks only have homocellular rays, the extant FAGACEOUS evergreen examples either have mild heterocellular rays or homocellular rays.

Fossil under investigation might be recognized as an evergreen *Quercus* species; however, it should have homocellular rays, according to Selmeier (1992b). Our specimen, on the other hand, possesses heterocellular rays.

Microscopic characters revealed from fossil wood under investigation shows similarities with fossil wood of *Castanopsis*, *Castanoxylon eschweilerense*, C. *indicum*, and C. *tertiarum* are diffuse porous; C. *philipii* has distinct heterocellular rays. *Castanoxylon zonatum* and *Castanopsis uchiuraensis* possess a flame-like pattern of latewood vessels. Castanopsis *guangxiensis* is diffuse porous and has aggregate rays. *Castanopsis nanningensis* has ring porous wood, scalariform plates, and has aggregate rays. *Castanea antiqua* and *Castanoxylon bavaricum* is distinctly ring porous with continuous early wood vessel zones. *Castanea protoantiqua* has wider (1–3 cells) rays.

Our fossil characterized by semi-ring porosity and radially arranged vessels is similar to *Castanopsis makinoi* (Ogura) however, tylosis commonly present in *Castanopsis makinoi* which makes our fossil wood slightly different from the *C. makinoi* hence assigned as a new species as ***Castanopsis ranikotensis*** specific epithet refers to locality (Table: 4.15).

Table 4:15 On the basis of anatomical features of specimen No. 108/Man/RK/11 the following wood fossil species reported in the world belongs to the same genus;

Sr. No.	Name of Family	Genus	Region Habitat	Age	Geographical Distribution	Reference
1.	**FAGACEAE**	*Castanopsis guangxiensis* Huang, Jin, Quan et Oskolski	Nanning Basin, Guangxi Province, South China. Yongning Formation	Oligocene	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Huang et al., 2018)
2.	**FAGACEAE**	*Castanopsis makinoi* Ogura	Guanghui and Hutiaotan Clay Forests, Yuanmou County, Yunnan Province ,China Lower part of the Yuanmou Formation	Pliocene	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Cheng et al., 2018)

3.	**FAGACEAE**	*Castanopsis nanningensis* Huang, Jin, Quan et Oskolski	Yongning Formation Nanning Basin, Guangxi Province, South China.	Oligocene (Upper)	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Huang et al., 2018)
4.	**FAGACEAE**	*Castanopsis uchiuraensis* Suzuki and Terada	Noto Peninsula, Japan	Miocene (Lower)	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Suzuki and Terada, 1996)
5.	**FAGACEAE**	*Castanopsis makinoi* Ogura	Amorimura, Nagano Prefecture, Japan	--	Europe and temperate Asia Temperate Asia (China), Japan, Russia	(Ogura, 1949)

4.6.5. Affinities and comparison with modern wood species

There are 120 species of *Castanopsis,* and they are found throughout tropical and subtropical Asia. The majority of evergreen broad-leaved forests in hills and sub-mountainous regions of south and southeast China are made up of about 58 species that are found along the Yangtze River region (Huang et al. 1999). Wood Taxonomists studied anatomical features the fossil species belongs to the family FAGACEAE *Castanopsis ranikotensis*. and compared its characteristics with the modern species and reported many species of the Modern species belong to the family FAGACEAE *Castanopsis ranikotensis*. Following is the brief of some of the genus related to the Wood Fossil specimen (Table: 4.16);

Table 4:16 On the basis of anatomical features of specimen 108/Man/RK/11 the following modern species reported in the world belong to the same genus;

Sr. No.	Name of Family	Genus	Region Habitat	Age	Geographical Distribution	Reference
1.	**FAGACEAE**	*Castanopsis acuminatissima* (Blume) A.DC. (KI RIUNG, KO-MAT, NEW GUINEA OAK)	Bangladesh to S. Central China and Papuasia Evergreen, Height to 40 m	Present	Central Asia Myanmar Asia-Pacific and Southeast Asia Vietnam, Cambodia, Laos, Thailand (Indochina) Indonesia, the Philippines, Malaysia, Brunei, Papua New Guinea, and the Solomon Islands make up Indomalesia.	(Phromprasit et al., 2016)

2.	**FAGACEAE**	*Castanopsis argyrophylla* King ex Hook. f. (YIN YE ZHUI)	Evergreen	Present	Central Asia **Pakistan**, India, and Sri Lanka Myanmar Asia-Pacific and Southeast Asia Vietnam, Cambodia, Laos, Thailand (Indochina)	(Phromprasit et al., 2016)
3.	**FAGACEAE**	*Castanopsis armata* (Roxb.) Spach	Arunachal Pradesh to Indo-China Tree Height up to 30m	Present	In Central Asia Sri Lanka, **Pakistan**, and India Burma The Pacific and Southeast Asia Cambodia, Vietnam, Laos, Thailand (Indochina)	(Phromprasit et al., 2016)

4.	**FAGACEAE**	*Castanopsis carlesii* (Hemsl.) Hayata (MI ZHU)	S. China to Vietnam, Taiwan	Present	Asia-Pacific and Southeast Asia Vietnam, Cambodia, Laos, Thailand (Indochina)	(Lee, 1968)
5.	**FAGACEAE**	*Castanopsis cuspidata*	Tree, Height from 20 to 30m	Present	Asia that is temperate and Europe Russia, Japan, and China in temperate Asia	(Sudo, 2007)
6.	**FAGACEAE**	*Castanopsis diversifolia* (Kurz) King ex Hook.f.	Tree, Height up to 30m, Diameter up 1200-200cm	Present	Southeast Asia and Pacific Thailand, Laos, Vietnam, Cambodia (Indochina)	(Sudo, 2007)

4.6.6. Paleoclimatology

(Huang et al., 2018) collected wood fossils specimens from Yongning Formation of Oligocene age, from Nanning Basin, Guangxi Province, South China. (Huang et al., 2018) found three new fossils species, out of which two species belongs to the genus *Castanopsis* (i. *Castanopsis nanningensis* and *Castanopsis guangxiensis*) and one specie related to *Lithocarpoxylon* (*L. nanningensis*). On the basis of their anatomical observations they suggested that *Castanopsi*s present in this region since late Oligocene. Presence of numerous Fagaceae family members were recorded with faint or without growth rings particularly in *Castanopsis nanningensis*. It suggests that Guangxi (South China) had a seasonal tropical climate that was probably monsoonal in the late Oligocene.

(Cheng et al., 2018) conducted research on the Pliocene fluvial lacustrine sediments of the Yuanmou Basin, Yunnan, which is located to the southeast of the Qinghai-Tibet Plateau, China. A wide variety of wood and animal fossils can be found in this location. Ten angiosperm species and three gymnosperm taxa were described by (Cheng et al., 2018). These included the following: *Cedreloxylon cristalliferum* Selmeier (Meliaceae), *Dalbergioxylon biseriatensis* sp. nov. (FABACEAE), *Lagerstroemioxylon yuanmouensis*, and *Castanopsis makinoi* (Ogura) Suzuki and Terada (Fagaceae). Cheng, Li, Jiang and Wang (Lythraceae), *Paraalbizioxylon sinica* sp. nov., P. *yunnanensis* sp. nov. (Fabaceae), *Pterocaryoxylon huxii* sp. nov. (Juglandaceae), *Zelkova wakimizui* (Watari) *Watari* (Ulmaceae), *Abies* sp. (Pinaceae), *Cephalotaxus* sp. (Cephalotaxaceae), and *Picea* sp. (Cheng et al., 2018) linked these species and previously discovered species with Nearest Living Relatives (NLRs) and found that in this region during Pliocene, subtropical broad-leaved deciduous vegetation were found at lower altitude. While in the middle altitude, subtropical broad-leaved evergreen vegetation including Castanopsis was found at mountains around the basin, while other genera were existed at high elevation. The NLRs' habits suggest that predominate environment was likely humid subtropical, which is distinct from the current hot and dry climate that supports savanna. Some hypotheses state that during this time, subtropical forests dominated Yunnan, whereas tropical rain forests thrived in southwest Asia and India. The elevated mountains of the Qinghai-Tibet plateau in western Yunnan probably acted as a barrier to exclude warm, humid air from the Indian Ocean, which had an impact on plant dispersal and distribution.

(Phromprasit et al., 2016), conducted research on seven modern species of genus *Castanopsis* collected from Northern Thailand. He described the anatomical features of these species. As per climatic data, Thailand has two different climates: a tropical monsoon climate in the south and southeast and a tropical savanna climate in the northern portion of the nation. These species existed in the Tropical savanna climate. Wood fossils species discovered from China revealed that they were found in the monsoonal climate during late Oligocene.

(Lee, 1968) made an effort to clarify the general and particular traits of Fagaceae wood as well as to gather information about the taxonomic relationships—which have been interpreted in a variety of ways—among some of the species that are found in Taiwan. Taiwan is home to 45 Fagaceae species, which are split into seven genera (Lin and Liu, 1965). 35 of these species were collected for research. Every species has a thorough description given, with special attention paid to the variations between species and genera. With the exception of the southern region, which has a tropical climate, these species are found in Taiwan's subtropical climate.

Fagaceae is a family of evergreen plants. Its' various genera including *Castanopsis* are found in the present tropical to subtropical zones in the world also present in Pakistan. It is average height is from 20 to 30m. While at places it grows up to 40m. Specimen No. 108/Man/Rk/11 designated as FAGACEAE *Castanopsis ranikotensis*, discovered from the Manchar Formation (Miocene), Ranikot Sindh, todays' barren land is the clear evidence of change of environment. It indicates that during Miocene time, this area has tropical to subtropical environment.

4.7. Summary of Paleo-climatic relation of wood fossils species with present living species

On the basis of anatomical analysis of Wood fossils selected from Manchar Formation of Miocene age, Ranikot area of Sindh, it could be suggest that during the period of Miocene and Pliocene climate of Sindh, probably warm-temperate to subtropical on the basis of comparison of identified wood fossils species with Nearest Living Relative (NLRs) species. (Table: 4.17). Nearest Living Relatives species of identified five wood fossils species including JUGLANDACEAE *Caryojuglandoxylon*, LEGUMINOSAEPAPILI-ONIDEAE *Dalbergioxylon*, BETULACEAE *Alnoxylon* sp. Nov, SAPINDACEAE *Aceroxylon* and Fagaceae *Castanopsis ranikotensis* are present in the warm-temperate to subtropical environment of the todays 'world. According to the Köppen-Geiger Climate Classification map of Pakistan, area of Sindh and maximum portion of Pakistan classified as a Arid, desert, hot (BWh) climate (1980-2016) (Fig. 4.16). Presence of these species in the Ranikot area is the clear indication of change in environment from past warm-temperate - subtropical to present arid, desert, hot climate.

Table 4:17 Summary of Paleo-climatic relation of wood Fossils species with Present living species;

Sr. No.	**Wood Fossil Specie**	**Present Specie**	**Present Climate in which it is found**	**Past Climate in which these Fossils discovered**	**Present Climate of Ranikot area**
1.	**JUGLANDACEAE *Caryojuglandoxylon***	*i. Carpinusdonghaensis* *ii. Betulajanggiensis* *iii. Caryacathayensis* Sarg. *iv. Caryacordiformis*	warm-temperate and subtropical	Could be warm-temperate and subtropical	Arid, desert, hot, (BWh) according to Köppen-Geiger Climate Classification (Fig. 4.16)
2.	**LEGUMINOSAEPAPILI-ONIDEAE *Dalbergioxylon***	i. *Dalbergiaassamica* ii. Benth. (ROSEWOOD) iii. *Dalbergiabaronii* iv. *Dalbergiabracteolata* Baker	humid subtropical Monsoonal wetter climate	Could be humid subtropical Monsoonal wetter climate	
3.	**BETULACEAE *Alnoxylon sp. nov.***	*i. Alnoxylon* sp *ii. Alnusacuminata* Kunth (ANDEAN ALDER) *iii. Alnusalnobetulasub* sp. *iv. Alnushirsuta* (Spach) Rupr. (ALDER)	tropical to subtropical forests	Could be warmer temperature in the early Oligocene	

4.	**SAPINDACEAE *Aceroxylon***	*i. Acer amoenum* Carr. *ii. Acer argutum* Maxim.*(POINTED-LEAF MAPLE)* ***iii.*** *Acer campbellii* (Pakistan)	cool-temperate	Warm-temperate and subtropical during the Miocene.	
5.	**Fagaceae *Castanopsis ranikotensis***	*i. Castanopsis acuminatissima* *ii. Castanopsis argyrophylla* iii.*Castanopsis carlesii* iv.*Castanopsis cuspidate* v. *Castanopsis diversifolia*	Seasonal tropical climate Monsoonal climate	Subtropical climatic region during Pliocene	

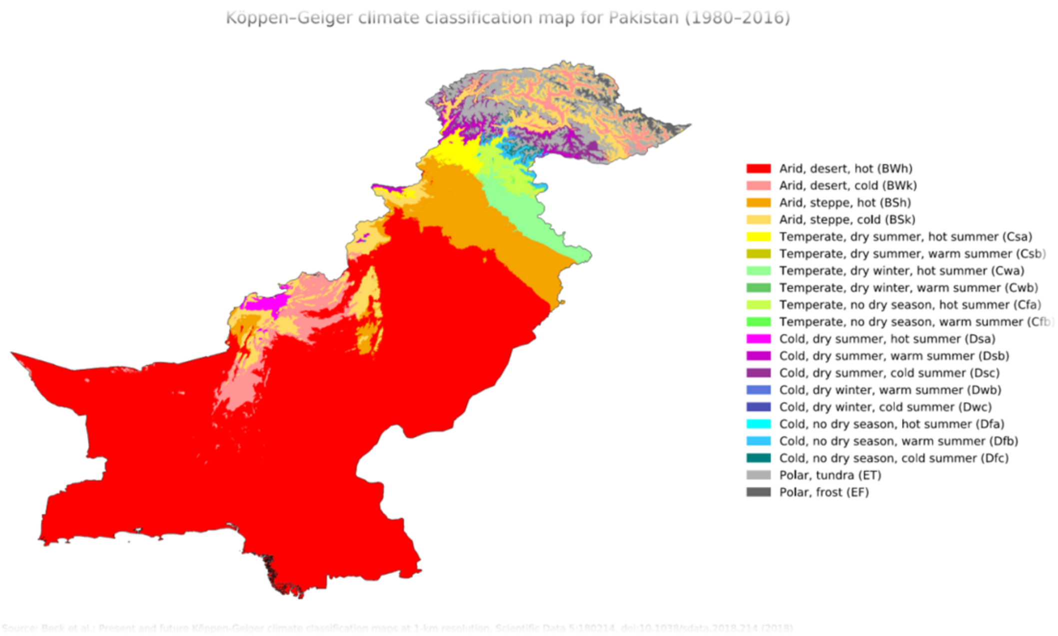


Figure 4.11 Köppen-Geiger Climate Classification map for Pakistan (1980-2016)

4.8. Isotopic analysis of Carbon^{13} ($\delta^{13}C$) for the specimens

Researchers from all over the world use $\delta^{13}C$‰ values extracted from plants in comparison with isotopic values of $\delta^{15}N$, $\delta^{14}C$, and $\delta^{18}O$ to illustrate environmental conditions for the past and present. Based on δ13C‰ values obtained from these researches, they contributed largely to describing and comparing the past climate with the present environmental conditions.

4.8.1. Values of $\delta^{13}C$‰ VPDB as an "Environmental Indicator"

(Basu et al., 2015) compared the ration of $\delta^{13}C$ in C_3 and C_4 modern plants to reconstruct the paleovegetational environment and found that the average bulk $\delta^{13}C$ values of C_3 plants are −29.6‰ ± 1.9‰, with a range of −32.6‰ to −19.2‰. (Kohn, 2010) collected 570 individual C3 plant species, Mean Annual Precipitation mm/yr (MAP) and Mean Annual Temperature (ºC) data from various altitudes and create a carbon isotopic model which illustrate that the carbon isotope compositions of C_3 plants vary greatly (-20 to -37‰, VPDB), which is typically due to a physiological reaction to aridity (anomalously high $\delta^{13}C$) and a combination of low light levels and recycling of leaf litter (anomalously low $\delta^{13}C$). Earth System Research Laboratories determined the values of $\delta^{13}C$ by comparing ratios of ^{13}C and ^{12}C for various environments such as for Oceans and atmosphere is -8‰, for Terrestrial biosphere is -26‰ and for Pee Dee Belemnite (PDB) is 0‰. (Basu et al., 2015) explained that by comparing the $\delta^{13}C$ of C_3 and C_4 plants that the $\delta^{13}C$ values of C_3 plants decreased as a result of the MAP increase. Conversely, the C_4 plants' $\delta^{13}C$ values show an inverse connection with MAP because of the high carbon leakiness value in the bundle sheath cell. C_3 and C_4 plants are directly affected by MAP.

Values of $\delta^{13}C$ in C_3 and C_4 plants (herbs and shrubs, trees, plants, and grasses) reflect the present and paleo-environmental conditions. C_3 and C_4 plants have included in the diet of many other herbivores in the past and present. $\Delta^{13}C$ marked isotopic fingerprints on the teeth, bones, and plants of prehistoric time. Many researchers analyzed the composition of $\delta^{13}C$ in the fossilized fragments of teeth and bones of present and prehistoric animals and plants to reconstruct the paleoclimate. Here, Carbon isotope acts an indicator of Diet and Ecology. (Tütken, 2011) conducted research on bones and teeth of *Brachiosaurus* sp, *Brachiosaurus brancai*., *Camarasaurus* sp., *Dicraeosaurus* sp., and other species of Dinosaurs of Late Jurassic of age, collected from USA and Tanzania. He also collected Fern, Tree fern and Cycad specimen to measure the values of $\delta^{13}C$ in these specimens to reconstruct the paleo- environmental conditions. He found the fingerprint of $\delta^{13}C$ in the teeth and bones of these extinct species and also in the plants he collected from various places. On the basis of his observation he described the range of $\delta^{13}C$ in terrestrial and aquatic plants (Fig. 4.17).

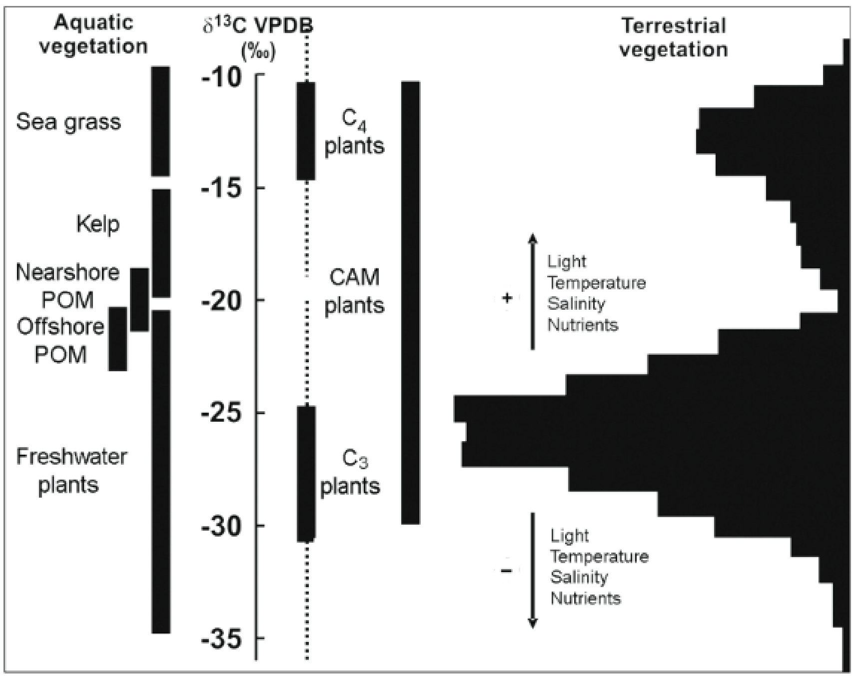


FIGURE 4.1. Carbon isotope composition of plants. Ranges of $\delta^{13}C$ values in extant terrestrial and aquatic plants are given. Thick vertical bars represent ranges in $\delta^{13}C$ values for terrestrial (Bender 1971; Deines 1980) and aquatic vegetation (Clementz et al. 2006 and references therein). The distribution of the $\delta^{13}C$ values of terrestrial C_3 and C_4 plants is also given in histogram form. Environmental influences and their effects on the $\delta^{13}C$ values of C_3 plants (Tieszen 1991; Heaton 1999; Gröcke 2002) are schematically shown. POM, particulate organic matter, a proxy for phytoplankton. *Modified after Clementz et al. (2006 and references therein).*

Figure 4.12 (Tütken, 2011) Model for describing the Range of δ13C in Terrestrial and Aquatic plants

4.8.2. Major differences between C_3, C_4 and CAM plants

C_3 plants initially developed "C_3 pathway" which is also referred as "Calvin cycle" and it is the most basic type of photosynthesis process which also known as the oldest one. In this process, first carbon compound produced three atoms hence the name "C_3 pathway". One useful method for turning CO_2 into carbon is the Calvin cycle. It effectively removes greenhouse gas (CO_2) from the environment. Plants are able to retain energy for longer time. A C_3 plant is an example of a typical photosynthesizing plant on Earth. In comparison to C_4 plants, the ideal temperature for photosynthesis is lower. The plant's stomata allow the enzyme Rubisco to absorb carbon dioxide, which it then fixes into sugar via the Calvin cycle. It encourages the growth of plants. When carbon dioxide is fixed by Rubisco, the Calvin cycle starts. The carbon dioxide fixation mechanism in C_3 plants is sluggish and only happens once. In C_3 plants, photosynthesis occurs when stomata are open and only in the presence of light. Due to the opening of stomata in C_3 plants, they not have any mechanism to combat photorespiration. In photorespiration which occurs at night, plants uses oxygen and to break the molecules of glucose to release energy and produce carbon dioxide. They do not have specialized anatomical structure that is called "Kranz anatomy" which is found in C_4 plants. Due to absence of Kranz anatomy, energy waste in large amount created by the process of photosynthesis. C_3 plants make up about 95% of all plants on Earth. Another name for them is temperate plants because they are common in temperate climate. C_3 plants requires cool and wet environment.

C_4 plants originated from C_3 plants. In C_4 Hatch and Slack pathway or C_4 cycle in which carbon compound produced four carbon atoms and hence called C_4. The low amounts of carbon dioxide in the atmosphere may have prompted the formation of the C_4 pathway, according to a number of evolutionary patterns. These plants thus have an evolutionary advantage due to the C_4 pathway. They have a specific kind of leaf anatomy and join the Calvin cycle by using the specialized enzyme called Phosphoenolpyruvate carboxylase (PEP enzyme). C_4 plants adopted many features with change of environment such as process of photosynthesis occurs mesophyll and bundle sheath cells while in C_3 plants this happens in only in mesophyll. Photosynthesis process is occurs even stomata are closed. Carbon dioxide fixation is faster. C_4 plants' leaves have specialized features are called "Kranz anatomy". In C4 plants, effects of photorespiration reduced by carrying out the process of the carbon dioxide fixation and Calvin cycle in separate cells. 5% green plants are C_4 plants. C_4 requires tropical and dry environment. C4 plants are found in tropical climate.

CAM plants "Crassulacean Acid Metabolism (CAM)" adopted the most modern features according to the environment. They are mostly found in the dry region where scarcity of water is common and water lose is probably a threat to the survival of plants. To combat this process, CAM plants collects sunlight during day time and fixes carbon dioxide during night time. In CAM plants effects of photorespiration controlled by taking fixing of carbon dioxide and Calvin cycle process at different times. On the basis of above discussion we could summarize that (Table: 4.18);

Table 4:18 Environmental conditions for C_3, C_4 and CAM Plants on the basis of $\delta^{13}C$

Sr. No.	C_3 Plants	C_4 Plants	CAM Plants
1.	Requires cool and wet climate. They also called temperate plants because they are commonly found in temperate region.	C_4 requires tropical and dry environment. C4 plants are found in tropical climate.	C4 plants are found in desert environments.
Values of $\delta^{13}C$‰ VPDB for C_3, C_4 and CAM Plants			
	C_3 Plants	**C_4 Plants**	**CAM Plants**
2.	-20‰ to -37‰ (Kohn, 2010)	-12‰ to -16‰ (O'Leary, 1988)	-10‰ to -20‰ (O'Leary, 1988)

4.8.3. Paleo-climatic environment for identified wood fossil species on basis of $\delta^{13}C$‰ VPDB

In this research, first ever in Pakistan, an attempt has made to establish a relation between anatomical observations of fossilized wood specimens with their $\delta^{13}C$ values to reconstruct the Paleoclimate of the study area and compare both values to authenticate the results. To obtained $\delta^{13}C$ values from the wood specimens, seven pulverized specimens sent to the Pakistan Institute of Nuclear Science and Technology (PINSTECH) for $\delta^{13}C$ Nuclear Magnetic Resonance (^{13}CNMR) isotopic analysis. Following results received from the PINSTECH (Table: 4.19);

Table 4:19 Results for Isotopic Analysis of Samples

Sr. No.	Sample ID	$\delta^{13}C$ (‰) (VPDB)*
1.	61	-28.35
2.	77	-27.14
3.	78	-23.63
4.	84	-26.67
5.	89	-22.43
6.	95	-25.79
7.	108	-22.16

Note: The upper limit of standard deviation of each measurement for $\delta^{13}C$ is ± 0.1 ‰

***VPDB:** The zero point of the carbon stable isotope scale, which is used to represent the relative abundance of 13C and 12C, is defined by the Vienna Pee Dee Belemnite (VPDB) isotope reference.

Wood fossils Isotopic Values of $\delta^{13}C$ VPDB falls within the limits of -20‰ to -37‰ described by the (Kohn, 2010) according to the results received from PINSTECH (Table: 4.18). These carbon isotopic values of $\delta^{13}C$ VPDB indicate that wood fossil specimens belong to C_3 plants. Relevancy of these isotopic values of fossilized wood specimens with the environment has illustrated with the help of model to establish their link with the environment (Fig. 4.18);

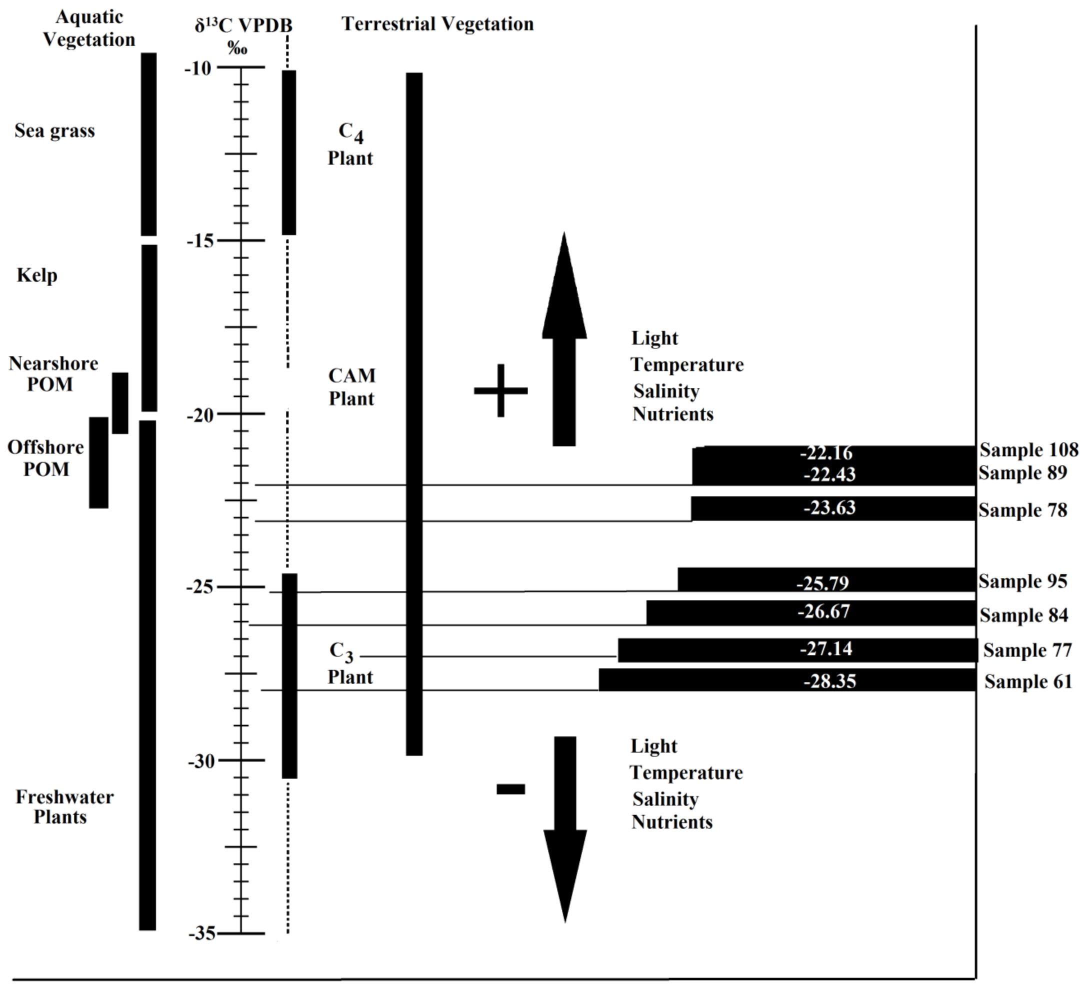
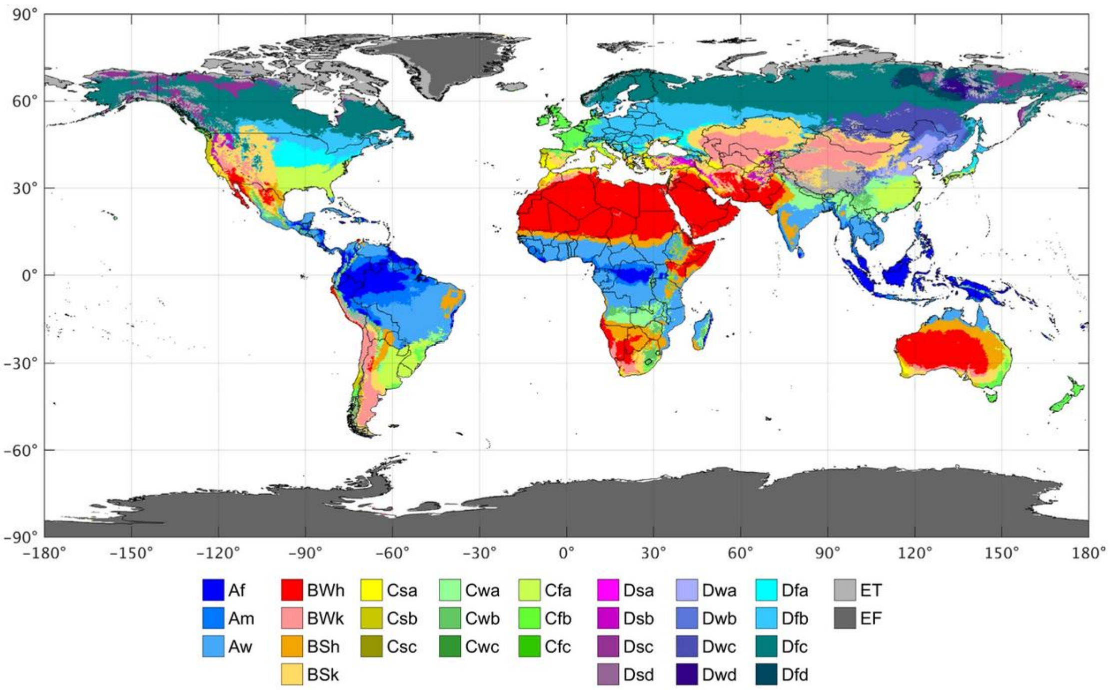


Figure 4.13 Relation of δ13C VPDB values of fossilized wood specimen with the environment (Modified after (Tütken, 2011)

In present time, Nearest Living Relatives (NLRs) of these wood fossil species reported in warm-temperate to cool, wet and Monsoonal climatic regions of the world (Table: 4.16). The areas where these NLRs have found received significant Mean Annul Precipitation (MAP), which provides favorable conditions to grow properly. Vegetation around the world dominated in the areas which have sufficient MAP. Values of carbon isotopes $\delta^{13}C$ VPDB effected by the average rainfall throughout the year. Average annual temperature of the year is also change due to the change in the rainfall which also influenced the distribution of vegetation around the world. Köppen Geiger chooses seasonal precipitation and temperature pattern of world for his climatic classification (Beck et al., 2018; Peel et al., 2007) (Fig. 4.19). Köppen climate classification scheme symbols described in (Table: 4.20).



New and improved Köppen-Geiger classifications. Part (a) shows the present-day map (1980-2016) The color scheme was adopted from Peel et al (2007).

Figure 4.14 Köppen-Geiger Climate Classification updated by (Beck et al., 2018). The color scheme adopted from (Peel et al., 2007).

Table 4:20 Köppen climate classification scheme symbols

Sr. No.	Symbol denoted for Climatic Group	Climatic Group (CHP and Yerlikaya, 2020)	Seasonal Precipitation type (CHP and Yerlikaya, 2020)	level of heat (CHP and Yerlikaya, 2020)	Symbols for Climate
1.	**A**	**Tropical**	**f** = Rainforest **m** = Monsoon **w** = Savanna , dry winter **s** = Savanna, dry summer	--	Af Am Aw
2.	**B**	**Dry**	**W** = Arid, Desert **S** = Semi- Arid, steppe	**h** = Hot **k** = Cold	BWh BWk BSh BSk
3.	**C**	**Temperate**	**w** = Dry winter **f** = No dry season **s** = Dry summer	**a** = Hot summer **b** = Warm summer **c** = Cold summer	Csa Csb Csc Cwa Cwb Cwc Cfa Cfb Cfc
4.	**D**	**Continental**	**w** = Dry winter **f** = No dry season **s** = Dry summer	**a** = Hot summer **b** = Warm summer **c** = Cold summer **d** = Very dry cold winter	Dsa Dsb Dsc Dsd Dwa Dwb Dwc Dwd Dfa Dfb Dfc Dfd
5.	**E**	**Polar**	--	**T** = Tundra **F** = Ice cap	ET EF

On basis of temperature and seasonal rainfall, Köppen-Geiger classified major areas of Pakistan as Arid, desert, hot (BWh), and while North-Eastern part of Pakistan including some upper part of Punjab and Khyber Pakhtunkhwa showed Arid, steppe, hot climate. Areas in the upper part of Punjab including capital territory of Islamabad exhibit temperate dry winter and hot summer climate. Distribution of vegetation in these areas depends upon climatic condition and has diverse verity due to the climatic changes. Nearest Living Relatives (NLRs) species of these identified species are present in the Northern part of Pakistan.

Now in the area of Sindh, Babul (*acacia-nilotia*) accounts for 60% of the tree species grown, followed by kandi (*prosopis-cinraria*) at 14%, mesquite (Prosopis-juliflora) at 12%, lai (tamrx-dioca) at 9%, and other species at 5%. These woodlands are disappearing quickly. These species presently found in the area of Sindh, survive in the extreme hot and dry climate. While NLRs of identified wood fossils species present in the upper regions of Pakistan, India, Bangladesh, Burma, Nepal, and southern part of China which have temperate climate (Fig. 4.19).

(Salma et al., 2012), distributed Pakistan into five climatic zones i.e., Zone A, Zone B, Zone C, Zone D, and Zone E, according to their mean annual temperature and Mean Annual rainfall/ Precipitation (MAP) mm/yr. Zone D, is categorized as the hottest and dry zone of the country with the maximum temperature recorded in Jacobabad and Sibbi. Areas of Bahawalpur, Khanpur, Multan, Rohri, and some parts of Thar Desert, included in this Zone. Whereas, Zone E comprised Coastal regions, Nawab Shah, Hyderabad, Karachi, Jiwani, and Pasni. These areas received minimum Mean Annual Precipitation (MAP) mm/yr due to dry climate and hottest temperature. As discuss earlier that due to the temperature and MAP vegetation diversity effects largely. Due to the climate of Zone E which also includes the study area, have Babul (acacia-nilotia), kandi (*prosopis-cinraria*) and mesquite (*Prosopis-juliflora*) type vegetation which could survive in the dry and hot climate in the scarcity of water and rainfall. Relationship between Paleoclimate of wood fossils species on the basis of $\delta^{13}C$ VPDB obtained through Carbon isotopic analysis and MAP of Sindh and world in (Fig. 4.19);

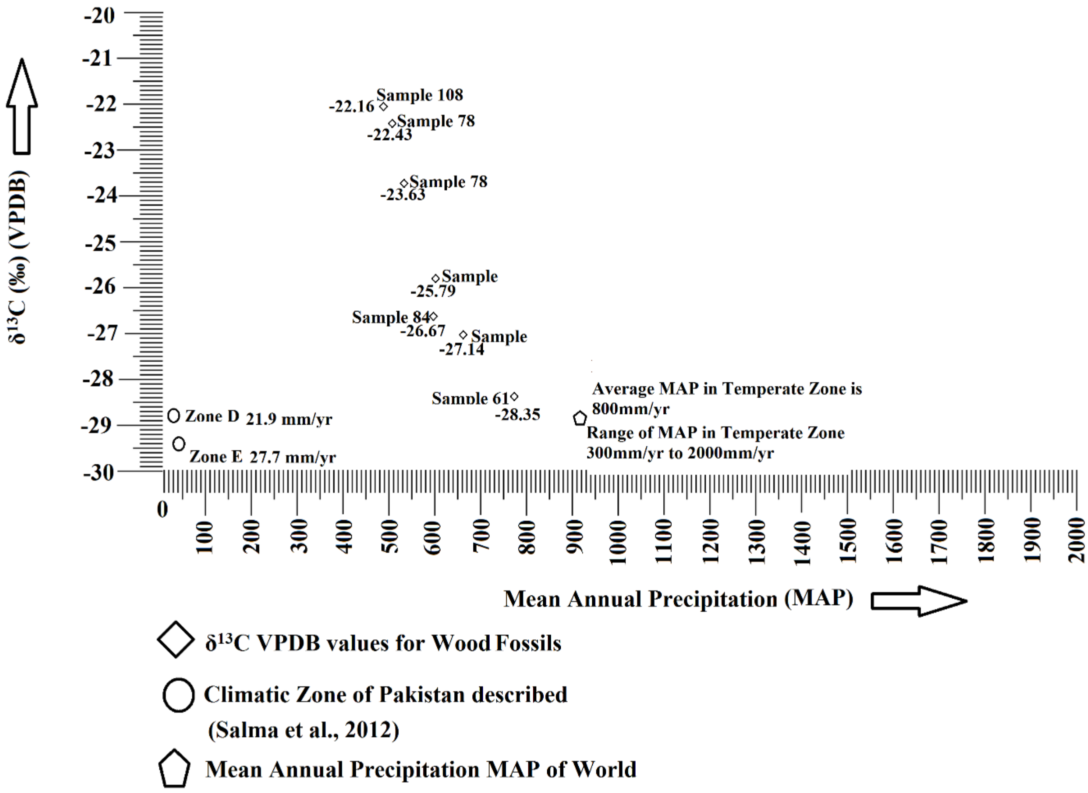


Figure 4.15 Relationship between δ13C‰ VPDB values of wood fossils and Mean Annual Precipitation (Salma et al, 2012)

On basis of this (Fig. 4.20), it could easily be idealized that identified wood fossils species belongs to the world's temperate regions. Temperate Zones of the world received 300mm/yr to 2000mm/yr rainfall. This phenomenon supports C_3 plants type vegetation requires sufficient rainfall to grow and develop. Relation between Carbon Isotopic $\delta^{13}C$ ‰VPDB values of wood fossils selected for analysis and Mean Annual Precipitation (MAP) clarifies that during the Miocene period, climatic conditions of the areas were warm-temperate, Monsoonal and wet that supported C_3 plants vegetation because identified species belongs to the C_3 type vegetation which is also called temperate vegetation (Fig. 4.21).

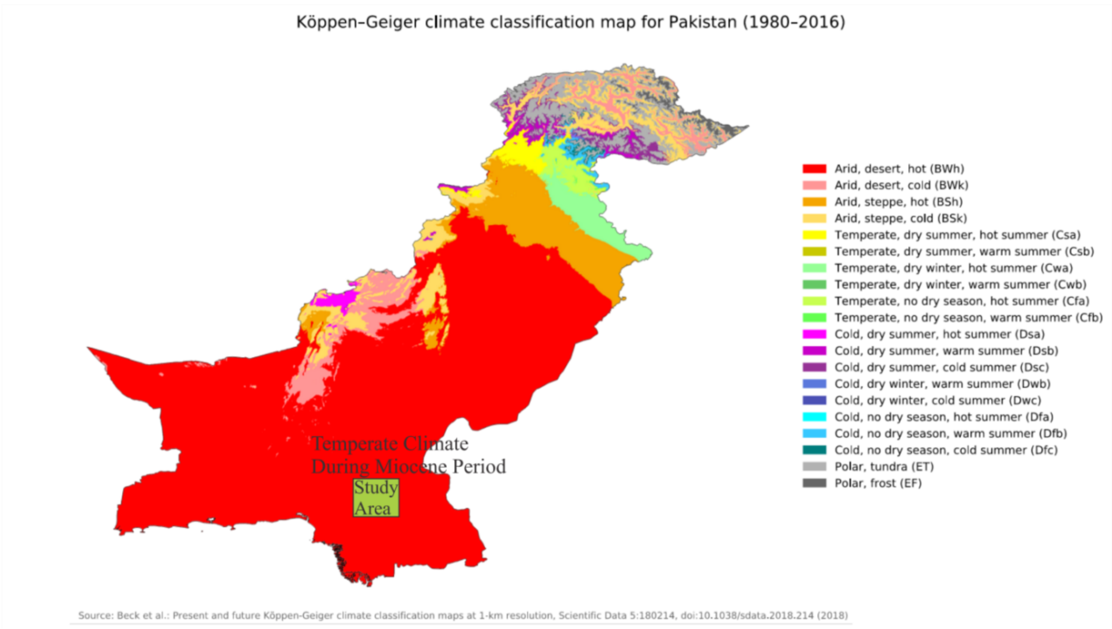


Figure 4.16 Paleo-climatic map: Temperate Climate during Miocene Period in the study area

CHAPTER 05

CONCLUSION AND FUTURE RECOMMENDATIONS

5.1. CONCLUSION

- Study area lies in Rani Kot, District Jamshoro, Sindh, southern part of Sindh or in the Lower Indus Basin of Pakistan.
- 115 Petrified wood fossils specimens collected from the Manchar formation (Miocene in age) during field and after careful examinations, 07 specimens selected for anatomical analysis and $Carbon_{13}$ isotopic studies.
- On the basis of anatomical observations, 05 species identified from the 07 specimens and **04 new wood fossils species** reported for the very first time from the area.
- Comparison of these identified species fossilized wood specimens has been made with the other same age wood fossils specimens in the world and with their Nearest Living Relatives (NLRs).
- On the basis of these comparisons with same age wood fossils and living species of same family and genus it is found that these identified wood fossils species belongs to the warm-temperate, Tropical to Subtropical, wet and Monsoonal climate.

- Presently, Nearest Living Relatives (NLRs) of these identified species are found in the Northern Part of Pakistan which receives plenty of rainfall. It is the clear indication that during Miocene period, area of Sindh had temperate climate.
- With the help of anatomical observation it is discovered that climate of Sindh is changed from temperate to Arid, Desert, and hot (BWh) type climate.
- Isotopic analysis of pulverized wood fossils specimens it is observed that analyzed wood fossils specimens belongs to the C_3 plants which have range limit of -20‰ to -37‰ for $\delta^{13}C$ ‰VPDB.
- C_3 plants also referred as a "Temperate plants" because their mainly grows in the temperate regions.
- Presence of these C3 plants wood fossils species in the study is also authenticate that during Miocene period this area had Temperate, Tropical to Subtropical, wet-Monsoonal Climate.
- Both anatomical observations and Carbon Isotopic analysis confirmed that Sindh had temperate climate during Miocene time and received sufficient rainfall with wet climate which provided support in their growth.

5.2. FUTURE RECOMMENDATIONS

i. More research is needed to explore the past climate of Pakistan on wide range by expending the comparison of wood fossils collected from others regions of Pakistan also.

ii. Other Isotopic indicators such Nitrogen, Oxygen and Carbon need also be used to compare the present climate with the past time.

REFERENCE

Ahmed, B., Rajput, M., and Soomro, N. (2007). Anogeissoxylon rehmanense sp. nov., a new fossil species of the family Combretaceae from Rehman Dhoro, District Jamshoro, Sindh, Pakistan. *Pakistan Journal of Botany*, 39(7), 2337-2344.

Ahmed, B., Rajput, M. T. M., Shah, N., & NOOR-UL-AIN, S. O. O. M. R. O. (2007). EUPHORIOXYLON THANOBOLENSIS SP. NOV. A NEW SPECIES OF FOSSIL WOOD FAMILY SAPINDACEAE FROM THANOBOLA KHAN DISTRICT JAMSHORO, SINDH, PAKISTAN. *Pak. J. Bot, 39*(7), 2317-2325.

Ahmed, S., Hussain, S., Qamar-uddin, A. G., & Ali, M. (2015). STUDY ON GENERAL GEOLOGY, FOSSILS AND CUT STONE OF THANO BULA KHAN, JAMSHORO, SINDH, PAKISTAN. *Gomal University Journal of Research*, 31(2)..

Ajaykumar11, B., Joseph, S., Abhilash, P. C., Mohan, M., Anitha, K., & Thomas, A. P. FOSSIL WOOD: AKEY TO THE PAST. WOOD: TYPES, PROPERTIES, AND USES, 169.

Ali, F., Shiq, Z., Rafique, A., Ali, B., & Iqbal, H. (2023). Palynostratigraphical and oceanic anoxic events investigation in the Lower Jurassic Black Shale, Indus Basin, Pakistan. *Journal of Himalayan Earth Sciences,* 56(2), 73.

Arain, B. A., and Rajput, M. T. M. (2014). Ougenioxylon chinjiensis sp. nov., a new fossil species of the family Leguminosae from Chinji Formation Salt Range, Punjab Pakistan. *American Journal of Plant Sciences, 5(26),* 3745-3751.

Asghar, H., Mughal, M. S., Khan, M. S., Abbas, S., Hanif, M., Hussain, G., and Hussain, A. (2021). Biostratigraphic investigation and depositional model of the

Late Thanetian Ranikot and the Ypresian Laki formations in the subsurface of the Southern Indus Basin, *Pakistan. Arabian Journal of Geosciences, 14(13), 1264.*

Bardet, M., and Pournou, A. (2015). Fossil wood from the Miocene and Oligocene epoch: chemistry and morphology. Magnetic Resonance in Chemistry, 53(1), 9-14.

Barefoot, A. C., and Hankins, F. W., 1982, Identification of modern and tertiary woods, Oxford University Press.

Barry, J. C., Behrensmeyer, A. K., Badgley, C. E., Flynn, L. J., Peltonen, H. A. N. N. E. L. E., Cheema, I. U., ... and Morgan, M. E. (2013). Chapter 15. The Neogene Siwaliks of the Potwar Plateau, Pakistan. In Fossil mammals of Asia: Neogene biostratigraphy and chronology (pp. 373-399). Columbia University Press.

Basu, S., Agrawal, S., Sanyal, P., Mahato, P., Kumar, S., and Sarkar, A. (2015). Carbon isotopic ratios of modern C3–C4 plants from the Gangetic Plain, India and its implications to paleovegetational reconstruction. Palaeogeography, Palaeoclimatology, Palaeoecology, 440, 22-32.

Bechtel, A., Gratzer, R., Sachsenhofer, R. F., Gusterhuber, J., Lücke, A., and Püttmann, W. (2008). Biomarker and carbon isotope variation in coal and fossil wood of Central Europe through the Cenozoic. Palaeogeography, palaeoclimatology, palaeoecology, 262(3-4), 166-175.

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., and Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific data, 5(1), 1-12.

Benner, R., Fogel, M. L., Sprague, E. K., and Hodson, R. E. (1987). Depletion of 13C in lignin and its implications for stable carbon isotope studies. Nature, 329(6141), 708-710.

Boureau, É., Furon, R., and Rosset, L. F. (1950). Contribution à l'étude des flores jurassiques d'Asie. Éditions du Muséum.

Brohi, I. A., SOLANGI, S., BABLANI, S., AGHEEM, M., SAHITO, A., and BROHI, A. (2012). Geological and Stratigraphical Studies of Dimension and Cut Stone Deposits Around Khanu Brohi and Khadhar Areas, District Jamshoro, Sindh. Pakistan. Sindh University Research Journal-SURJ (Science Series), 44(4).

Buurman, P. (1972). Mineralization of fossil wood. Scripta geologica, 12, 1-43.

Charbonnier, S., Garassino, A., Pasini, G., Métais, G., Merle, D., Bartolini, A., ... and Marivaux, L. (2013, April). Early Paleogene decapod crustaceans from the Sulaiman and Kirthar ranges, Pakistan. In Annales de Paléontologie (Vol. 99, No. 2, pp. 101-117). Elsevier Masson.

Cheng, Y. M., Wang, Y. F., Liu, F. X., Jin, Y. G., Mehrotra, R. C., Jiang, X. M., and Li, C. S. (2018). The Neogene wood flora of Yuanmou, Yunnan, southwest China. IAWA journal, 39(4), 427-474.

Choi, S. K., Kim, K., Jeong, E. K., Terada, K., Suzuki, M., and Uematsu, H. (2010). Fossil woods from the Miocene in the Yamagata Prefecture, Japan. IAWA journal, 31(1), 95-117.

Chowdhury, K. A., Ghosh, S. S., and Kazmi, M. H. (1960). Pahudioxylon bankurensis gen. et sp. nov.-A fossil wood from the Miocene bed of Bankura District, West Bengal, India. Proceedings of the Natural Institute for Sciences of India B, 26, 22-28.

Chowdhury, K. A., and Tandon, K. N. (1964). A fossil wood of Terminalia tomentosa W. & A. from the Tertiary of Burma. Annals of Botany, 28(3), 445-450.

Chowdhury, K. A., and Ghosh, S. S. (1946). On the anatomy of Cynometroxylon indicum gen. et sp. nov., a fossil dicotyledonous wood from Nailalung, Assam. In Proc. Nat. Inst. Sci. India (Vol. 12, No. 8, pp. 435-447).

CHP, E. İ., and Yerlikaya, A. J. P., 2020, From Wikipedia, the free encyclopedia, v. 31, p. 4.

Cossmann, Maurice. The Mollusca of the Ranikot series. Office of the Geological Survey, 1909.

Croft, William J. Under the microscope: a brief history of microscopy. Vol. 5. World Scientific, 2006.

Denk, T., Güner, H. T., and Bouchal, J. M. (2019). Early Miocene climate and biomes of Turkey: Evidence from leaf fossils, dispersed pollen, and petrified wood. Palaeogeography, Palaeoclimatology, Palaeoecology, 530, 236-248.

Frederiksen, N. O. (1990). Palynological contribution to geologic mapping of coal-bearing upper Paleocene rocks in the Lower Indus coal region, Pakistan (No. 90-243). US Geological Survey,.

Frederiksen, Norman O. "Middle and Late Paleocene angiosperm pollen from Pakistan." Palynology 18, no. 1 (1994): 91-137.

Friedman, J. M., Stricker, C. A., Csank, A. Z., and Zhou, H. J. P., Palaeoclimatology, Palaeoecology, 2019, Effects of age and environment on stable carbon isotope ratios in tree rings of riparian Populus, v. 524, p. 25-32.

García Guinea, J., and Martínez Frías, J. (1998). Cell-hosted pyrite framboids in fossil woods. Naturwissenschaften: Organ der Max-Planck-Gesellschaft zur Foerderung der Wissenschaften: Organ der Gesellschaft deutscher Naturforscher und Aerzte, 85, 78.

Gentis, N., Licht, A., Boura, A., De Franceschi, D., Win, Z., Aung, D. W., and Dupont-Nivet, G. (2022). Fossil wood from the lower Miocene of Myanmar (Natma Formation): palaeoenvironmental and biogeographic implications. Geodiversitas, 44(28), 853-909.

Gessler, A., Ferrio, J. P., Hommel, R., Treydte, K., Werner, R. A., and Monson, R. K. (2014). Stable isotopes in tree rings: towards a mechanistic understanding of isotope fractionation and mixing processes from the leaves to the wood. Tree physiology, 34(8), 796-818.

Ghosh, S. S., and Ghosh, A. K. (1959). Dipterocarpoxylon malavii sp. nov., a new fossil record from the Pliocene of Kutch. Sci. Cult, 25, 328-332.

Ghosh, S. S., and Kazmi, M. H. (1961). Pahudioxylon sahnii sp. nov., a new fossil record from the Miocene (?) of Tripura. Sci. Cult, 27, 96-98.

Ghosh, S. S. (1956). On a fossil wood belonging to the genus Dipterocarpus. Science and Culture, 21, 691-692.

Gingras, M. K., Bann, K. L., Maceachern, J. A., Waldron, J., and Pemberton, S. G. (2007). A conceptual framework for the application of trace fossils.

Gottwald, H. (1981). ANATOMISCHE UNTERSUCHUNGEN IN PLIOZAENEN HOELZERN AUS WILLERSHAUSEN BEI GOETTINGEN.

Grosser, D. (1977). Die Hölzer Mitteleuropas: ein mikrophotographischer Lehratlas (pp. 1-208). Berlin, Germany: Springer-Verlag.

Güngör, Y., Akkemik, Ü., Kasapçı, C., and Başaran, E. (2019). Geology and woods of a new fossil forest from the early Miocene of Gökçeada (Turkey). Forestist, 69(1), 22-34.

Hakro, A. A., Xiao, W., Yan, Z., and Mastoi, A. S. (2018). Provenance and tectonic setting of E arly E ocene S ohnari M ember of L aki F ormation from southern I ndus B asin of P akistan. Geological Journal, 53(5), 1854-1870.

Hercman, H., Szczerba, M., Zawidzki, P., and Trojan, A. (2019). Carbon isotopes in wood combustion/pyrolysis products: experimental and molecular simulation approaches. Geochronometria, 46(1), 111-124.

Hon, J. A. B. (2010). EVOLUTION OF LARGER BENTHIC FORAMINIFERA DURING THE PALEOCENE-EARLY EOCENE INTERVAL IN THE EAST TETHYS (INDUS BASIN, PAKISTAN).

Hook, B. A., Halfar, J., Bollmann, J., Gedalof, Z. E., Rahman, M. A., Reyes, J., and Schulze, D. J. (2015). Extraction of α-cellulose from mummified wood for stable isotopic analysis. Chemical Geology, 405, 19-27.

Huang, L., Jin, J., Quan, C., and Oskolski, A. A. (2018). Mummified fossil woods of Fagaceae from the upper Oligocene of Guangxi, South China. Journal of Asian Earth Sciences, 152, 39-51.

Humphries, D. W. (1992). The preparation of thin sections of rocks, minerals, and ceramics.

Itoh, T. (1995). Anatomical description of japanese hardwoods: I [-IV]. Wood Research Institute.

Jagirani, S. S., Bai, L., Jagirani, M. D., Panhwar, S. A., and Neupane, B.(2020). Sedimentological Study of Manchar Formation, Kari Buthi Section, Northern Laki Range, Southern Indus Basin, Pakistan.

Jeong, E. K., Kim, K., Suzuki, M., and Kim, J. W. (2009). Fossil woods from the lower coal-bearing formation of the Janggi Group (Early Miocene) in the Pohang Basin, Korea. Review of Palaeobotany and Palynology, 153(1-2), 124-138.

Khan, S. A., Ahmed, B., Salehatahir, S., Rajput, M. T., Arshad, F., and Naz, H. (2017). ANGIOSPERMIC FOSSILPOLLEN ISOLATED FROMTHE SHELE OF BARA FORMATION, RANI KOT, SINDH, PAKISTAN. Pak. J. Bot, 49(5), 1757-1761.

Kłusek, M., and Pawełczyk, S. (2014). Stable carbon isotope analysis of subfossil wood from Austrian Alps. Geochronometria, 41, 400-408.

Kohn, M. J. (2010). Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo) ecology and (paleo) climate. Proceedings of the National Academy of Sciences, 107(46), 19691-19695.

Kureshy, A. J. G. M., 1984, The foraminiferal stratigraphy of Laki formation (Early Eocene) of Pakistan, v. 11, no. 1, p. 231-236.

Lee, C. S. (1968). Comparative wood anatomy of the Fagaceae of Taiwan.

Leland, C., Andreu-Hayles, L., Cook, E. R., Anchukaitis, K. J., Byambasuren, O., Davi, N., ... and Pederson, N. (2023). Impacts of climate and tree morphology on tree-ring stable isotopes in central Mongolia. Tree Physiology, 43(4), 539-555.

Lukens, W. E., Eze, P., and Schubert, B. A. (2019). The effect of diagenesis on carbon isotope values of fossil wood. Geology, 47(10), 987-991.

Mädler, K. (1939). Die pliozäne flora von Frankfurt am Main (Vol. 446). Alexander Doweld.

Malkani, M. S., Khosa, M. H., Alyani, M. I., Somro, N., Zafar, T., Arif, J., and Aleem, M. Z. (2017). Revised Stratigraphic Setup and Mineral Deposits of Kirthar Basin (Lower Indus Basin), Pakistan. Lasbela University Journal of Science and Technology, 6, 54-84.

Malkani, M. S., and Mahmood, Z. J. G. S. o. P., Memoir, 2017, Stratigraphy of Pakistan, v. 24, p. 1-134.

Mangi, J., Khan, S. A., Soomro, N., Naz, H., and Panhwer, M. (2020). WOOD OF BURSEROXYLON FOSSIL FROM BARA FORMATION OF RANI KOT FORT AREA, DISTRICT JAMSHORO SINDH, PAKISTAN: Institute of Plant Sciences, University of Sindh, Jamshoro, Pakistan. Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences, 36(1), 1-7.

Martinelli, L. A., Almeida, S., Brown, I. F., Moreira, M. Z., Victória, R. L., Sternberg, L. S. L., ...and Thomas, W. W. (1998). Stable carbon isotope ratio of tree leaves, boles and fine litter in a tropical forest in Rondonia, Brazil. Oecologia, 114, 170-179.

Martínez, C., Pérez-Lara, D. K., Avellaneda-Jiménez, D. S., Caballero-Rodríguez, D., Rodríguez-Reyes, O., Crowley, J. L., & Jaramillo, C. (2024). An early Miocene (Aquitanian) mangrove fossil forest buried by a volcanic lahar at Barro Colorado Island, Panama. Palaeogeography, Palaeoclimatology, Palaeoecology, 637, 112006.

Matysová, Petra. "Study of fossil wood by modern analytical methods: case studies." (2016).

Mehrotra, R. C., Bera, S. K., Basumatary, S. K., and Srivastava, G. (2011). Study of fossil wood from the Middle–Late Miocene sediments of Dhemaji and Lakhimpur districts of Assam, India and its palaeoecological and palaeophytogeographical implications. Journal of earth system science, 120, 681-701.

Merle, D., Pacaud, J. M., Métais, G., Bartolini, A., Lashari, R. A., Brohi, I. A., ... and Welcomme, J. L. (2014). Volutidae (Mollusca: Gastropoda) of the Lakhra Formation (Earliest Eocene, Sindh, Pakistan): systematics, biostratigraphy and paleobiogeography. Zootaxa, 3826(1), 101-138.

Métais, G., Antoine, P. O., Marivaux, L., and Welcomme, J. L. The Paleocene/Eocene boundary and biostratigraphy of the Ranikot Group in the Karachi Arch (Sindh, Pakistan).

Metcalfe, Charles Russell, and Laurence Chalk. "Anatomy of the dicotyledons, Vols. 1 & 2." (1950): lxiv+-1500.

Moltesen, M., and Glyptotek, N. C. (1994). The Lepsius marble samples. Ny Carlsberg Glyptotek.

Morgan, M. E., Behrensmeyer, A. K., Badgley, C., Barry, J. C., Nelson, S., and Pilbeam, D. (2009). Lateral trends in carbon isotope ratios reveal a Miocene vegetation gradient in the Siwaliks of Pakistan. Geology, 37(2), 103-106.

Müller-Stoll, W. R., and Mädel, E. (1959). Betulaceen-Hölzer aus dem Tertiär des pannonischen Beckens..

Mustoe, G. E. (2018). Non-mineralized fossil wood. Geosciences, 8(6), 223.

Navale, G. K. B. (1956). Sapindoxylon indicum sp. nov., a new fossil wood from the Tertiary beds of South India

Noor-Ul-Ain, S., Arain, B. A., Rajput, M. T. M., and Tahir, S. S. (2016). Ormosioxylon chinjiensis sp. nov., a new fossil wood of family Fabaceae from the Chinji formation Salt Range Punjab, Pakistan. Pak. J. Bot, 48(2), 595-599.

Noor-ul-Ain, S., Arain, B. A., Rajput, T., and Hassaney, S. S. (1848). A NEW PETRIFIED WOOD MILLETTIOXYLON SINDHIENSIS SP. NOV.(FABACEAE) FROM THANOBOLA KHAN, SINDH, PAKISTAN. Soil Biology & Biochemistry, 42, 2010.

Nordt, L., Tubbs, J., and Dworkin, S. (2016). Stable carbon isotope record of terrestrial organic materials for the last 450 Ma yr. Earth-science reviews, 159, 103-117.

Nuttall, W. L. F. (1925). The stratigraphy of the Laki Series (Lower Eocene) of parts of Sind and Baluchistan (India); with a description of the larger foraminifera contained in those beds. Quarterly Journal of the Geological Society, 81(1-4), 417-453.

O'Leary, M. H. (1988). Carbon isotopes in photosynthesis. Bioscience, 38(5), 328-336.

Ogura, Y. (1949). A fossil of Castanopsis-type from the Tertiary of Nagano Prefecture. Journal of Japanese Botany, 24, 15-18.

Outerbridge, W. F., Frederikeen, N. O., Khan, M. R., Khan, R. A., Qureshi, H. J., Khan, M. Z., and Niamatullah, K. S. (1991). The Sohnari Formation in southern Pakistan. US Geological Survey Bulletin, 1935, 27-34.

Parven, K., Soomro, N., Lashari, R. A., & Ashrad, F. (2022). Xylotomical Comparision of Fossil Wood with Living Wood of the Sapotaceae Family, from Manchar Formation Exposed at Thano Bula Khan, Jamshoro, Sindh, Pakistan.. Journal of Quality Assurance in Agricultural Sciences, 2(01), 90-97.

Peel, M. C., Finlayson, B. L., and McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and earth system sciences, 11(5), 1633-1644.

Peterson, S. E. Thin-Section Petrography.

Petrescu, I., and Nuţu, A. (1969). Asupra unui lemn de Alnoxylon in colecţia Muzeului Deva. Sargetia, Acta Musei Devensis, sr. Sc. Nat, 6, 223-229.

Phromprasit, P., Vajrodaya, S., and Kermanee, P. (2016). Species identification of some Castanopsis (D. Don) Spach (Fagaceae) species from Northern Thailand using wood characteristics. Thai Forest Bulletin (Botany), 44(2), 88-100.

Poole, I. (2000). Fossil angiosperm wood: its role in the reconstruction of biodiversity and palaeoenvironment. Botanical Journal of the Linnean Society, 134(1-2), 361-381.

Prakash, U., and Barghoorn, E. S. (1961). Miocene fossil woods from the Columbia basalts of Central Washington. Journal of the Arnold Arboretum, 42(2), 165-203.

Prakash, U., and Navale, G. K. B. (1962). Terminalioxylon chowdhurii sp. nov.: A new fossil dicotyledonous wood from the Tertiary rocks of Assam.

Prakash, U. (1968). Miocene fossil woods from the Columbia Basalts of central Washington, III. Palaeontographica Abteilung B, 183-200.

Rage, J. C., Metais, G., Bartolini, A., Brohi, I. A., Lashari, R. A., Marivaux, L., ... and Solangi, S. H. (2014). First report of the giant snake Gigantophis (Madtsoiidae) from the Paleocene of Pakistan: paleobiogeographic implications. Geobios, 47(3), 147-153.

Rajput, M. T. M., and Carolin, R. C. (1988). The genus Dampiera (Goodeniaceae): Systematic arrangement, nomenclatural notes and new taxa. Telopea, 3(2), 212-213.

Ramanujam, C. G. K., and Rao, M. R. R. (1966). The occurrence of Cynometroxylon indicum Chowdhury and Ghosh from the Cuddalore sandstone series. Current Science, 35(6), 158-159.

Raza, S. M., Barry, J. C., Meyer, G. E., & Martin, L. (1984). Preliminary report on the geology and vertebrate fauna of the Miocene Manchar Formation, Sind, Pakistan. Journal of Vertebrate Paleontology, 4(4), 584-599.

Raza, S. M., Barry, J. C., Meyer, G. E., & Martin, L. (1984). Preliminary report on the geology and vertebrate fauna of the Miocene Manchar Formation, Sind, Pakistan. Journal of Vertebrate Paleontology, 4(4), 584-599.

Rehmatullah, C. H. (1971). Studies of the silicified wood from the Tertiary rocks of Sindh (Doctoral dissertation, M. Phil. thesis, University of Sindh).

Robinson, S. A., and Hesselbo, S. P. (2004). Fossil-wood carbon-isotope stratigraphy of the non-marine Wealden Group (Lower Cretaceous, southern England). Journal of the Geological Society, 161(1), 133-145.

Rößler, R., Trümper, S., Noll, R., Hellwig, A., and Niemirowska, S. (2021). Wood shrinkage during fossilisation and its significance for studying deep-time lignophytes. Review of Palaeobotany and Palynology, 292, 104455.

Rugmai, W., and Grote, P. J. (2023). Paleovegetation of a Late Middle Pleistocene Fossil Site in Northeastern Thailand. Tropical Natural History, 23, 61-72.

Salma, S., Rehman, S., and Shah, M. A. (2012). Rainfall trends in different climate zones of Pakistan. Pakistan Journal of Meteorology, 9(17).

Salomón, R. L., Rodríguez-Calcerrada, J., De Roo, L., Miranda, J. C., Bodé, S., Boeckx, P., and Steppe, K. (2023). Carbon isotope composition of respired CO2 in woody stems and leafy shoots of three tree species along the growing season: physiological drivers for respiratory fractionation. Tree Physiology, 43(10), 1731-1744.

SanFilipo, J. R., Wnuk, C., Fariduddin, M., Ahmad, M., Khan, S. A., Chandio, A. H., and Khan, R. A. (1992). Potential for the occurrence of thick lignite deposits in the Thar Desert and adjacent lower Indus plain, Sindh Province, Pakistan (No. 92-576). United States Dept. of the Interior, Geological Survey,.

Sass, U. G. W., Wils, T., Helle, G., Schleser, G. H., and van Bergen, P. F. (2004). The use of stable isotope dendrochronology for environmental interpretations from tree-ring patterns in sub-fossil bog oaks. In TRACE. Tree Rings in Archaeology, Climatology and Ecology. Vol. 2 (pp. 94-99).

Schoch, W., Heller, I., Schweingruber, F. H., and Kienast, F. (2004). Wood anatomy of central European Species. Birmensdorf, Switzerland: Swiss Federal Institute for Forest.

Schönfeld, G. (1947). Hölzer aus dem Tertiär von Kolumbien.

Schweingruber, F. H. (1990). Anatomy of European woods. Anatomy of European woods.

SHABAB ALI KHAN, B. A., RAJPUT, M. T., and TAHIR, S. S. (2016). Andiroxylon thanobolensis sp. nov. a new species of fossil wood of family Fabaceae from manchar formation exposed near Thanobola Khan, district Jamshoro, Sindh, Pakistan. Pak. J. Bot, 48(1), 249-253.

Shar, M., Trimizi, S. A. S., and Ahmed, B. (2007). Shoreoxylon ranikotensis sp. nov. A New Species of Fossil Wood Dipterocarpiaceae from Ranikot Fort Area, District Jamshoro, Sindh, Pakistan. Pakistan Journal of Botany, 39, 2327-2335..

Siddiqui, S. N., Naz, H., and Niaz, O. (2022). Planktic Foraminiferal Study of Jhimpir Area, Sohnari Member (Laki Formation), Southern Indus Basin, Pakistan. Journal of Development and Social Sciences, 3(2), 762-772.

Sigleo, A. C. (1978). Organic geochemistry of silicified wood, Petrified Forest National Park, Arizona. Geochimica et Cosmochimica Acta, 42(9), 1397-1405.

Silvester, W. B. (1977). Dinitrogen fixation by plant associations excluding legumes.

Singh, M., and Ghosh, P. (2023). Isotopic Proxy to Identify Climate Change During the Anthropocene. In Climate Change Impacts on Natural Resources, Ecosystems and Agricultural Systems (pp. 549-563). Cham: Springer International Publishing.

Soomro, N., Arain, B. A., and Rajput, M. T. M. (2016). Albizzioxylon chinjiensis sp. nov., a new fossil species of the family Leguminosae from Chinji formation salt range, Punjab Pakistan. GEOMATE Journal, 11(28), 2838-2843.

Soomro, N., Jillani, N. S., Quereshi, S. T., Mangi, J. U., Arain, B. A., and Rajput, M. T. (2017). Discovery of Miocene Wood from Manchar Formation, Lagerstroemioxylon thanobolensis Sp. Nov. of Family Lythraceae, Thanobola Khan District Jamshoro, Sindh, Pakistan. Sindh University Research Journal-SURJ (Science Series), 49(3), 557-562.

Soomro, N., Mangi, J. U., Panhwer, M., Jatoi, G. H., Khuhro, S. A., Khokhar, Q., ... and Shaikh, N. (2021). Anatomical characteristics of fossil wood collected from the Manchar Formation (Miocene), Thano Bula Khan, Sindh, Pakistan. Italian Botanist, 11, 1-8.

Soomro, N. U. A., Mangi, J. U., Jamali, A. R., Jillani, N. S., Arain, B. A., and Rajput, M. T. M. (2016). Dichrostachyoxylon chinjiensis sp. nov., a new fossil species of the family Fabaceae from Chinji formation, Salt Range, Punjab, Pakistan. Sindh University Research Journal (Science Series), 48(4), 803-808.

Sorby, H. C. (1849). On the Microscopical Structure of the Calcareous Grit of the Yorkshire Coast. Proceedings of the Yorkshire Geological Society, 3(1), 197-206..

Srivastava, R., and Suzuki, M. (2001). More fossil woods from the Palaeogene of northern Kyushu, Japan. IAWA journal, 22(1), 85-105.St. John, R. N. J. E. G., 1927, Replacement vs. impregnation in petrified wood, v. 22, no. 7, p. 729-739.

Stepanova, A. V., Odintsova, A. A., Rybkina, A. I., Rostovtseva, Y. V., and Oskolski, A. A. (2022). Mummified Wood of Juniperus (Cupressaceae) from the Late Miocene of Taman Peninsula, South Russia. Plants, 11(15), 2050.

Sudo, S. (2007). Wood anatomy in Japan since its early beginnings. IAWA journal, 28(3), 259-284.

Suzuki, M., and Terada, K. (1996). Fossil wood flora from the lower Miocene Yanagida formation, Noto Peninsula, central Japan. IAWA journal, 17(4), 365-392.

Suzuki, M. (1976). Some fossil woods from the Palaeogene of northern Kyushu. The botanical magazine= Shokubutsu-gaku-zasshi, 89, 59-71.

Suzuki, M. (1988). Wood structure of Himalayan Plants. The Himalayan Plants, 1, 341-379.

Takahashi, A., and Suzuki, M. (1988). Two new fossil woods of Acer and a new combination of Prunus from the Tertiary of Japan. The botanical magazine= Shokubutsu-gaku-zasshi, 101, 473-481.

Taylor, E. L., Taylor, T. N., and Krings, M. (2009). Paleobotany: the biology and evolution of fossil plants. Academic Press.

Tütken, T. (2011). The diet of sauropod dinosaurs: Implications from carbon isotope analysis of teeth, bones, and plants In: Klein N, Remes K, Sander M, editors. Biology of the Sauropod Dinosaurs: Understanding the Life of Giants.

Ullah, S., Hanif, M., Radwan, A. E., Luo, C., Rehman, N. U., Ahmad, S., ... and Ashraf, U. (2023). Depositional and diagenetic modeling of the Margala Hill Limestone, Hazara area (Pakistan): Implications for reservoir characterization using outcrop analogues. Geoenergy Science and Engineering, 224, 211584.

van Bergen, P. F., and Poole, I. (2002). Stable carbon isotopes of wood: a clue to palaeoclimate?. Palaeogeography, Palaeoclimatology, Palaeoecology, 182(1-2), 31-45.

Vredenburg, E. W. (1909). Note on the stratigraphy of the Ranikot Series. Pal. Indica, NS, III, Mem. I: 5, 19.

WATARI, S. (1952). Dicotyledonous woods from the Miocene along the Japan-Sea side of Honshu. J. Fac. Sci. Univ. Tokyo, Sect. III, 6, 97-134.

Wheeler, E. A., and Baas, P. (1998). Wood identification-a review. IAWA journal, 19(3), 241-264.

Wheeler, E. A., and Dillhoff, T. A. (2009). The middle Miocene wood flora of Vantage, Washington, USA.

Wheeler, E. A., Gasson, P. E., and Baas, P. (2020). Using the InsideWood web site: potentials and pitfalls. IAWA Journal, 41(4), 412-462.

Wheeler, E. A., and Manchester, S. R. (2007). Review of the wood anatomy of extant Ulmaceae as context for new reports of late Eocene Ulmus woods. Bulletin of Geosciences, 82(4), 329-342.

Williams, M. D. (1959, May). 19. Stratigraphy of the Lower Indus Basin, West Pakistan. In World Petroleum Congress (pp. WPC-8019). WPC.

Wnuk, C., SanFilipo, J. R., Chandio, A. H., and Fatmi, S. F. (1993). The stratigraphy and coal resource potential of the Bara Formation in the Fort Ranikot area, Sindh Province, Pakistan; a progress report (No. 93-256). US Geological Survey,.

Wolfe, J. A. (1978). A paleobotanical interpretation of Tertiary climates in the Northern Hemisphere: Data from fossil plants make it possible to reconstruct Tertiary climatic changes, which may be correlated with changes in the inclination of the earth's rotational axis. American scientist, 66(6), 694-703.

Zijlstra, J. S., Flynn, L. J., and Wessels, W. (2013). The westernmost tarsier: A new genus and species from the Miocene of Pakistan. Journal of human evolution, 65(5), 544-550.