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Late Quaternary plant macrofossil assemblages from the Besigaon section of the Gokarna Formation, Kathmandu Valley, central Nepal

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ABSTRACT

Plant macrofossil investigation was carried out on the Late Quaternary sediments of the Kathmandu Valley, central Nepal. The fluvial-deltaic to fluvio-lacustrine deposits of the Kathmandu Basin are found to be rich in plant macrofossil assemblages. A total of 66 taxa from 38 families were identified to genus and some of them up to species level from five different macrofossil bearing layers (BG-1 to BG-5) from the 33 m thick Besigaon section belonging to the Gokarna Formation exposed at the northern part of the basin. The lower half of the exposed section is completely devoid of macrofossil horizons, however the upper half yielded a significant amount which could be used for climatic interpretation. The characteristic feature of the Besigaon section is the dominance of angiosperms in the lower and middle horizons (BG-1, BG-2, BG-3) but gymnosperms in the upper horizons (BG-4, BG-5). The dominance of angiosperms such as *Carpinus*, *Alnus*, *Pyracantha*, *Quercus* subgen. *Cyclobalanopsis*, *Eurya* and *Zizyphus* suggest the deposition of the lower and middle horizons in warm temperate climatic condition. The humid phase is documented during deposition of the BG-3 and BG-4 horizons with the findings of *Selaginella remotifolia* and wetland aquatic taxa such *Carex*, *Schoenoplectus*, *Nymphoides indica*. In contrast, the upper horizons dominated by gymnosperms such as *Abies*, *Pinus*, *Picea smithiana*, *Tsuga dumosa* and *Taxus wallichiana* represent cold and humid climate. The macrofossils from Besigaon section suggest minor fluctuation in climate from warm to cold temperate phase with increasing humidity during the Late Pleistocene.

Keywords: Paleoclimate, Late Pleistocene, plant macrofossils, Kathmandu Valley

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INTRODUCTION

The Kathmandu Valley, an intermontane basin in the Lesser Himalayan crystalline nappe is hosting fluvio-deltaic to fluvio-lacustrine sediments of Plio-Pleistocene to Holocene age (Yoshida and Igarashi 1984, Yoshida and Gautam 1988, Sakai et al. 2001, Sakai et al. 2008). The basin contains thick unconsolidated siliciclastic sediments, reaching a depth of more than 500 m in the central part (Fujii and Sakai 2002). Owing to a great potentiality to study the past climate change in this region, Vishnu-Mittre and Sharma (1984), Igarashi et al. (1988), Nakagawa et al. (1996), Fujii and Sakai (2001), Paudayal and Ferguson (2004), Paudayal (2005, 2006), Bhandari and Paudayal (2007) carried out palynological investigations from the different outcrops of the valley and interpreted the vegetation and climate during the Plio-Pleistocene. Study of pollen is one of the important basic tools for the reconstructions of climate and vegetation of the geological past (Birks 1981, 2003). The sediments exposed in the valley also contain well preserved plant macrofossils (Ooi 2001, Bhandari et al. 2009, 2010). An important advantage of macrofossil is the feasibility of correct identification of plants to a much lower taxonomic level. The lower taxonomic level of identification and the narrower range of ecological requirements of the taxa, the more detailed is the paleoclimate and environmental reconstruction (Kienast et al. 2001). Being comparatively large and heavy, an additional advantage of plant macrofossil study is that they are usually not transported far away from the sources (Kienast et al. 2001; Birks 1973, 2001) compared to pollen types which could be transported from great distances. A detailed stratigraphic study of the macrofossil assemblages clarifies the history of extant vegetation that was accompanied with environmental change since the Late Pleistocene. Based on the results obtained from the plant macrofossil analysis, this study attempts to reconstruct the environmental conditions and in particular vegetation and climate during the deposition of the Gokarna Formation during the Late Pleistocene epoch.

GEOLOGICAL SETTING

The Kathmandu Valley located in the central part of Nepal is almost hemi-spherical (30 km x 25 km) in shape. It is enclosed by mountain ranges such as Shivapuri towards north, Nagarjun towards north-west and Phulchauki towards south. The primitive lake of the Kathmandu Valley is regarded to be relatively small and confined to the southern

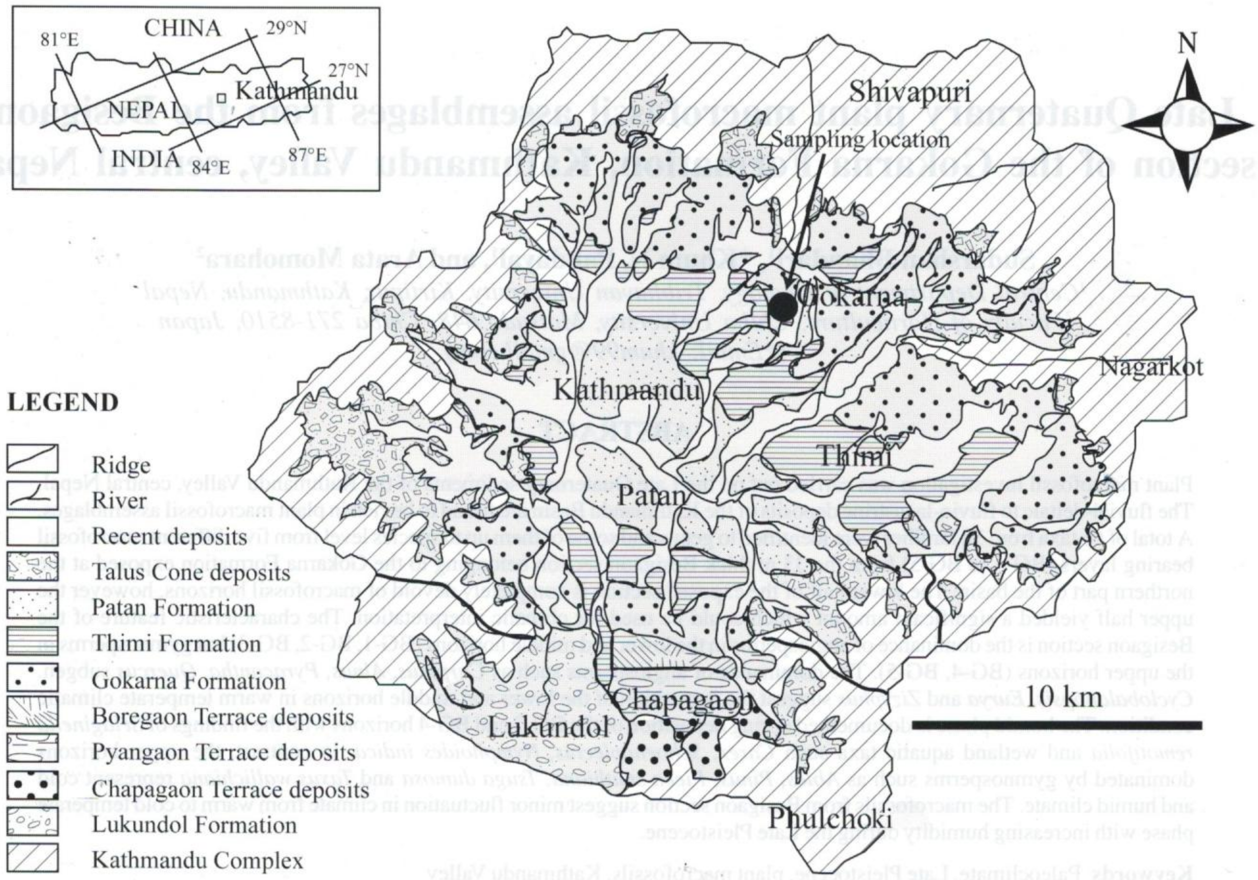

Fig. 1: Geological map of the Kathmandu Valley (after Yoshida and Igarashi 1984, Yoshida and Gautam 1988) with the sample location within the Gokarna Formation

part of the valley. The lake started receiving sediments from surrounding hills thus producing the deposits belonging to the Lukundol Formation (Kizaki 1994). This primitive lake was supposed to be an older Kathmandu Lake. As the Mahabharat Range in the south started rising, the Kathmandu Basin tilted northwards leading to the gradual shift of the lake towards north. The formerly deposited Lukundol Formation thus inclined with the tilt of the basin. Unlike older lake, the younger Kathmandu Lake covered the large area of the valley and the younger sediments like Kalimati, Dharmasthali, Gokarna, Tokha, Thimi and Patan formations were subsequently deposited (Yoshida and Igarashi 1984, Dongol 1985, Yoshida and Gautam 1988, Sakai 2001, Sakai et al. 2008). The basement rocks, forming surrounding mountains, consists of sedimentary rocks of the Paleozoic Phulchauki Group in the south and Pre-cambrian gneiss distributed in the north of the basin which is referred to as Kathmandu Complex (Stöcklin and Bhattarai 1980).

The Gokarna Formation, constituting the middle part of the sedimentary sequence of the Kathmandu Valley comprises the alternating layers of carbonaceous clay, silt, massive to parallel and large scale cross-stratified, fine to coarse grained sands and occasional gravel layers, deposited in a fluvio-deltaic and lacustrine environment. This formation is well exposed at a section in Besigaon (27^0 44' 10.8" N and 85^0 22' 42.5" E) at an altitude of 1335 m just behind the Nepal Medical College in the northern part of the Kathmandu Valley (Fig. 1). The thickness of this section is about 33 m and is composed of alternating layers of clay, silt and fine to coarse sand (Fig. 2). The sand layers are massive, parallel and cross stratified, fine to coarse grained with occasional gravel and pebble layers. The

Fig. 2: Outcrop of the Gokarna Formation at Besigaon

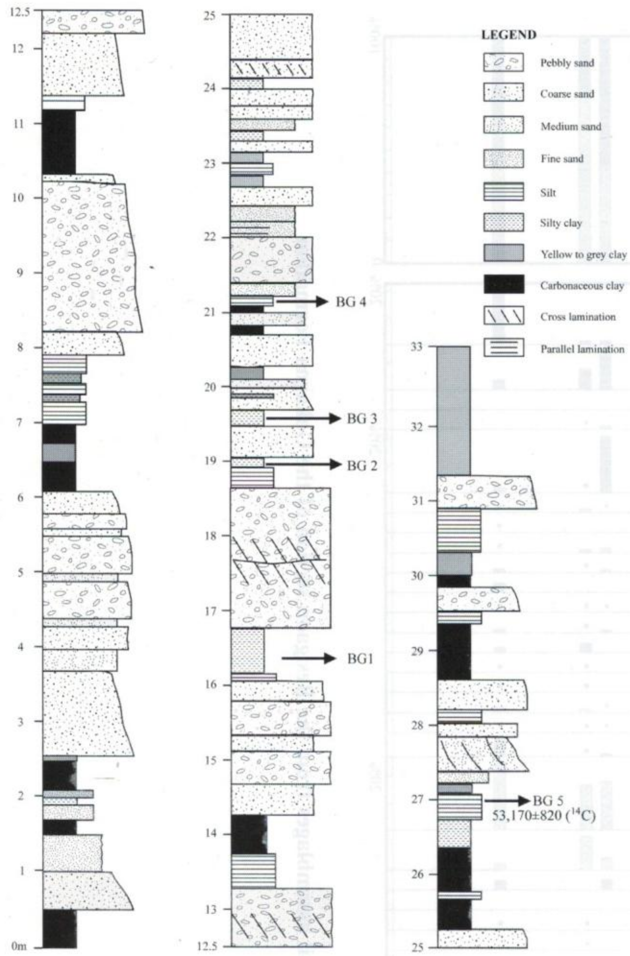

Fig. 3: Lithostratigraphic column of the Gokarna Formation at Besigaon section with the sampling layers (BG 1—BG 5) and ^{14}C dating results

proportion of clay in this section is comparatively lower than that of the Dhapasi section. These sediments can be subdivided into cross-laminated and parallel-laminated sand or sandy gravel beds with lenticular bodies of fluvial channel facies, black silt beds with intercalations of very fine to fine sand layers of marsh or flood plain facies and sand, sandy gravel or alternating sand and sandy silt beds with large scale tabular cross-stratification, wave ripple lamination and hummocky cross-stratification of delta front facies (Gajurel et al. 2007, Sakai et al. 2008).

While the total thickness of this section reaches 33 m, the first plant macrofossil assemblage zone (BG-1) was found at the height of 16.4 m from the bottom. The plant macrofossil assemblage zones BG-2 and BG-3 were within a range of 1 m in between 19 m and 19.6 m. The sampling horizons BG-4 and BG-5 were present at the height of 21.2 m and 27 m from the bottom, respectively (Fig. 3). A single nut of *Corylus ferox* recovered from macrofossil assemblage zone (BG-5) was dated using an Accelerator Mass Spectrometer (AMS) at Paleo Labo Co. Ltd., Japan. The radiocarbon age of the nut was found to be 53,170 ± 820 years BP.

MODERN VEGETATION

The flora in the Kathmandu Valley is highly influenced by human population while native vegetation can still be seen on the surrounding mountains. The valley floor contains few preserved forests such as Rajnikunj forest in Gokarna, Pashupati-Guheswori forest, Bajrabarahi forest etc. Small patches of stretched forest are distributed in Swayambhu, Hattiban and Nagarjun area. These forests contain the species growing in the moist habitat along the valley and valley floor, and on the north facing slopes (Tabata 1986). The common indigenous trees of the valley floor area are *Schima wallichii*, *Fraxinus floribunda*, *Syzygium jambos*, *Alnus nepalensis*, *Acer laevigatum*, *Pittosporum napaulensis*, *Litsea lanuginosa*, *Aesculus* sp. etc. *Pinus roxburghii* is also found in the basin floor mainly on the gravelly fan deposits. *Schima-Castanopsis* forest is common in the mountain slope between 1500 m to 1800 m. Oak-laurel forest occurs between 1800 m to 2400 m. The evergreen taxa such as *Quercus lanuginosa*, *Quercus semicarpifolia* and other species of *Quercus* are common in this altitudinal range (Stainton 1972, Malla et al. 1976). The conifers such as *Pinus wallichiana*, *Abies spectabilis* and *Tsuga dumosa* are very rarely distributed around the top of the mountains.

MATERIAL AND ANALYTICAL METHODS

The macrofossils are generally preserved in sediments such as silt, sandy silt and micaceous fine sand. About five kilograms of organic rich sediments were collected from each macrofossil horizon and brought to the laboratory of Central Department of Geology, Tribhuvan University, Kirtipur, Nepal. The sediments were then suspended in water in order to disperse the aggregates. The dispersed residue was washed and sieved in water using a 0.5 mm sieve to remove inorganic particles from plant fragments. Then, the residue on 0.5 mm were again washed in distilled water and sorted by different mesh sizes of 4 mm, 2 mm, 1 mm, 0.5 mm and 0.35 mm to facilitate observation. Macrofossils were picked up under binocular microscope (OLYMPUS SZ-PT) at x100 magnification using brush and needle. The seeds, fruits and leaves were identified as much as to genus and/or species level and the light microscope photographs of each individual taxon were taken with a NIKON Digital Camera DXM 1200F attached to the microscope. For the proper identification, the fossil seeds and fruits were compared on the basis of reference slides made from the extant herbarium specimen. Literature sources used for identification of fruits and seeds are Berggren 1969, 1981, Anderberg 1994, Manchester 1994, Martin and Barkley 1973, Nakayama et al. 2000, Velichkevich and Zastawniak 2006, 2008. The frequency of plant macrofossil taxa (Fig. 4) has been graphically rendered by using the software DMD (Draw up Microfossil Diagram, version 2.2).

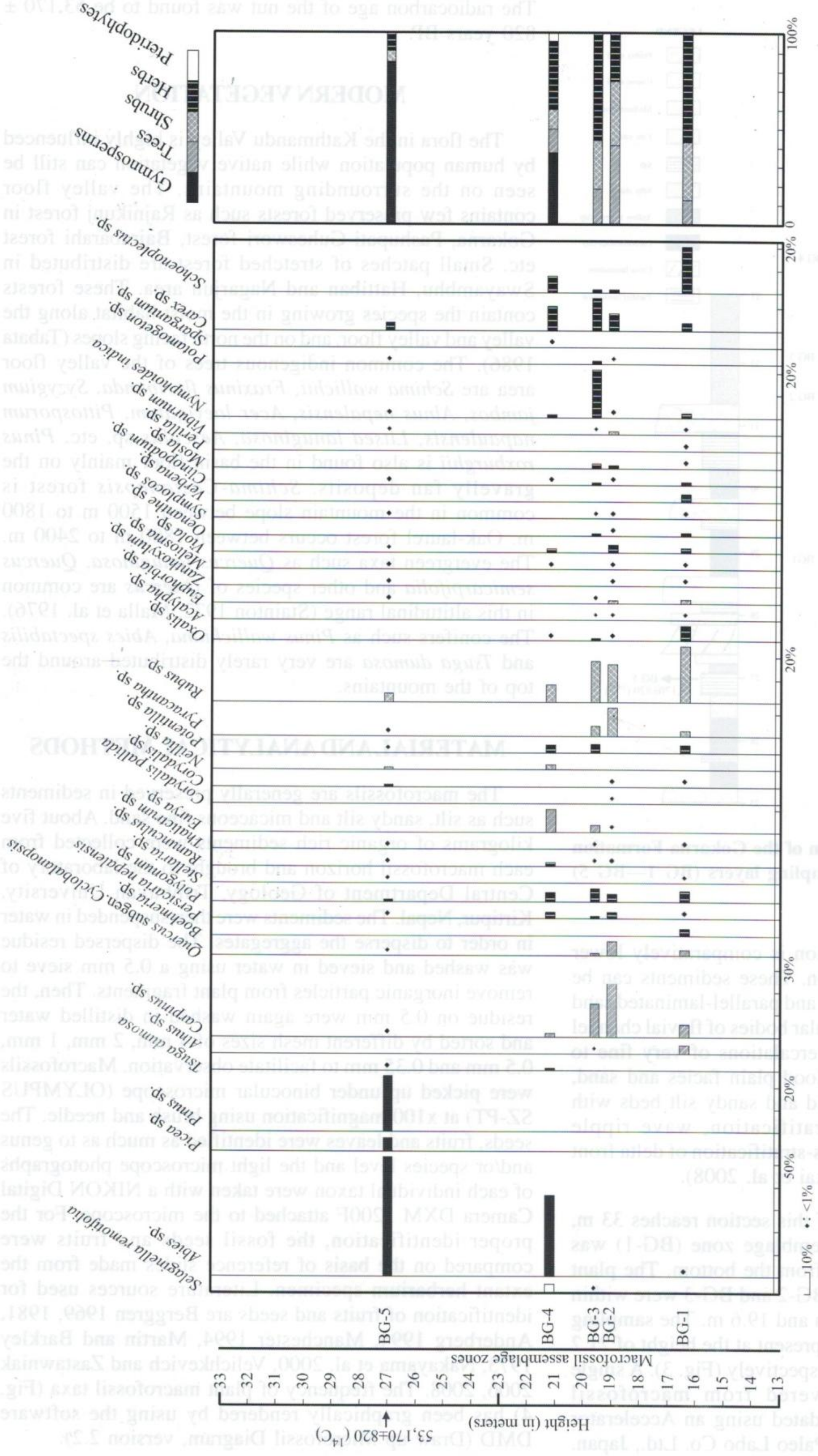

Fig. 4: Percentage diagram of the plant macrofossil assemblages from the Besigaon section of the Gokarna Formation

RESULTS OF PLANT MACROFOSSIL ANALYSIS

The results of the plant macrofossil investigation from the Besigaon section of the Gokarna Formation are listed in Table 1. In total, 66 taxa (Figs. 5-7) belonging to 38 families were identified to the genus and a few to the family level (for the morphological description, see Bhandari et al. 2009, 2010). Five plant macrofossil zones (Figs. 3 and 4; BG1–BG5) were distinguished on the basis of the constituents of fossil fruits and seeds in each zone which are listed and described below.

Macrofossil assemblage zone BG-1

This fossil assemblage zone is characterized by the dominance of fossil fruits and seeds of herbs and shrubs over trees. The dominant shrubs are *Rubus* (24.2%) and *Pyracantha* (2.4%). Of the herbaceous plants, *Schoenoplectus* (19.8%), *Oxalis* (6.5%) and *Polygonum* sp. (4.8%) are the dominant taxa. The other common herbs are *Potentilla* (3.6%), *Carex* (3.1%), *Verbena* (3.4%), *Boehmeria* (2.9%), *Viola* (2.2%), *Euphorbia* (1.7%) and *Clinopodium* (1.4%). *Oenanthe*, *Persicaria nepalensis*, *Stellaria*, *Solanum*, *Acalypha* and *Eleusine indica* are the other noted herbaceous taxa. Few fossil remains of trees are available from this zone. The dominant arboreal taxa are *Carpinus* (5.3%), *Alnus* (3.6%) and *Quercus* subgen. *Cyclobalanopsis* (2.4%). The other woody angiosperms such as *Meliosma* and *Zanthoxylum* are present in trace amount. *Abies* (0.2%) is the only gymnosperm present in this zone.

Macrofossil assemblage zone BG-2

This zone is represented by the abrupt increase in the constituents of woody angiosperms. *Carpinus* (31.9%) is the most dominant taxon in this zone. *Quercus* subgen. *Cyclobalanopsis* (6.2%) is the next important constituents along with *Meliosma*, *Zanthoxylum*, *Eurya* and *Mallotus philippinensis*. Of the shrubs, *Rubus* (16.0%) and *Pyracantha* (11.9%) are the dominant taxa. *Viburnum*, *Symplocos* and *Zizyphus* are the common shrubs in this zone. *Sabia* and *Vitis* are the shrubby vines. *Carex* (7.2%), *Polygonum* (3.5%), *Viola* (3.3%) and *Persicaria nepalensis* (2.9%) are the common herbs. The other herbaceous taxa are *Schoenoplectus*, *Mosla*, *Ranunculus*, *Acalypha*, *Oxalis, Ajuga* etc. The conifers are totally absent in this macrofossil assemblage zone.

Macrofossil assemblage zone BG-3

This macrofossil zone is characterized by the dominance of woody angiosperms. *Rubus* (17.7%) and *Pyracantha* (4.5%) are the dominant shrubs. Among the trees, *Carpinus* (16.4%), *Eurya* (3.5%), *Quercus* subgen. *Cyclobalanopsis* (1.2%) and *Mallotus philippinensis* are the important constituents. *Carex* (13.7%), *Polygonum* (5.7%), *Potentilla* (3.7%) are the important herbaceous taxa. *Oxalis* (1.3%) *Schoenoplectus* (1.3%), *Persicaria nepalensis* (1.0%), *Oenanthe* (1.0%), *Acalypha* (0.8%) and *Ranunculus* (0.3%) are the other notable herbs. *Nymphoides indica* (20.5%) and *Potamogeton* (1.3%) are the common aquatic taxa.

Macrofossil assemblage zone BG-4

This zone is represented by the reappearance and dominance of gymnosperms over angiosperms. *Abies* (34.9%) is the most dominant taxon in this fossil assemblage zone. *Tsuga dumosa* (1.2%) is the other conifer. Of the angiosperm trees, *Eurya* (9.9%) and *Carpinus* (2.4%) are the important constituents along with *Zanthoxylum* and *Mallotus philippinensis*. *Rubus* (7.6%), *Neillia* (2.3%) are the notable shrubby taxa. Among the herbaceous taxa, *Carex* (10.5%), *Schoenoplectus* (7.0%), *Polygonum* (4.1%), *Persicaria nepalensis* (3.0%), and *Ranunculus* (1.7%) are the important contributors.

Macrofossil assemblage zone BG-5

The trend of increament in the composition of gymnosperm continues in this zone as well. *Abies* (51.8%), *Pinus* (24.1%) and *Picea smithiana* (6.2%) are the dominant taxa along with *Tsuga dumosa* and *Taxus wallichiana*. Of the woody angiosperms, *Carpinus*, *Corylus ferox*, *Quercus* subgen. *Cyclobalanopsis*, *Lindera*, *Morus*, *Cornus* and *Zanthoxylum* are represented in minor amount. *Rubus* (3.7%) is an important contributor within shrub. The other common shrubs are *Pyracantha*, *Berchemia*, *Sambucus*, *Viburnum* and *Neillia*. Among the herbs *Carex* (3.4%), *Polygonum*, *Corydalis* and *Ranunculus* (each 1%) are the common taxa. *Persicaria nepalensis*, *Potentilla*, *Stellaria*, *Thalictrum*, *Euphorbia*, *Ajuga*, Labiatae, *Viola* and *Eleusine indica* are (<1% each) the other noted herbs. The aquatic herbs are represented by *Potamogeton*, *Myriophyllum* and *Nymphoides indica*.

PALAEOCLIMATIC INTERPRETATION

The richness of the fossil in one horizon and scarcity in other certainly does not give the complete picture of the floral composition of that time. However, certain inferences could be made about the vegetation growing around the depositional basin. Organic-rich deposits were completely absent from the lower part, however, we could find some layers rich in plant macrofossils in the middle and upper part of this exposure.

The macrofossil assemblage zone BG-1 is dominated by the shrubby and herbaceous taxa over the woody angiosperms. *Abies*, representing in trace amount is the only gymnosperm taxa from cold temperate zone. *Rubus* is the most dominant angiosperm taxa in this zone. The other common angiosperms are *Carpinus*, *Alnus*, *Quercus* and *Pyracantha*, the common taxa of warm temperate region. Hence, it is concluded that this horizon was deposited during a temperate phase.

The zone BG-2 is dominated by trees over shrubs and herbs. *Carpinus* and *Quercus* subgen. *Cyclobalanopsis* are

Table 1: List of plant macrofossils from the Gokarna Formation (Besigaon section)

Taxa with their families	Part	Plant macrofossil assemblage zones									
		BG 1		BG 1		BG 1		BG 1		BG 1	
		total sum	(%)	total sum	(%)	total sum	(%)	total sum	(%)	total sum	(%)
Pteridophyta											
Selaginella remotifolia Spring (Selaginellaceae)	macrospore					1	0.3	7	4.1		
Gymnospermae											
Taxus wallichiana Zucc. (Taxaceae)	seed									2	0.1
Abies sp. (Pinaceae)	leaf	1	0.2					60	34.9	1010	51.8
	seed									2	0.1
Picea smithiana (Wall.) Boiss. (Pinaceae)	leaf									120	6.2
Pinus sp. (Pinaceae)	needle									470	24.1
Tsuga dumosa (D. Don) Eichler (Pinaceae)	leaf							2	1.2	8	0.4
Angiospermae-Dicotyledonae											
Alnus sp. (Betulaceae)	fruiting scale	15	3.6								
Alnus sp. (Betulaceae)	nutlet					1	0.3				
Carpinus sp. (Betulaceae)	nutlet	22	5.3	155	31.9	56	14.0	3	1.7	3	0.2
Corylus ferox Wall. (Betulaceae)	nut									1	0.05
Quercus subgen. *Cyclobalanopsis* (Fagaceae)	nut/cupule	10	2.4	30	6.2	4	1.0			4	0.2
Morus sp. (Moraceae)	endocarp					1	0.3			5	0.3
Boehmeria sp. (Urticaceae)	fruit	12	2.9								
Persicaria nepalensis (Meisn.) H.Gross (Polygonaceae)	fruit	2	0.5	14	2.9	4	1.0	5	3.0	14	0.7
Persicaria thunbergii (Sieb. et Zucc.) H.Gross (Polygonaceae)	fruit			1	0.2	2	0.5				
Polygonum sp. (Polygonaceae)	fruit	20	4.8	17	3.5	23	5.7	7	4.1	20	1.0
Stellaria sp. (Caryophyllaceae)	seed	3	0.7							2	0.1
Chenopodium album L. (Chenopodiaceae)	seed	2	0.5								
Lindera sp. (Lauraceae)	endocarp									1	0.05
Ranunculus sp. (Ranunculaceae)	fruit			4	0.8	1	0.3	3	1.7	18	0.9
Thalictrum sp. (Ranunculaceae)	fruit	3	1.0			1	0.3			12	0.6
Eurya sp. (Theaceae)	seed			3	0.6	12	3.0	17	9.9		
Corydalis pallida (Thunb.) Pers. (Papaveraceae)	seed			1	0.2						
Corydalis sp. (Papaveraceae)	seed	4	1.0	1	0.2					21	1.1
Neillia sp. (Rosaceae)	seed							4	2.3	20	1.0
Potentilla sp. (Rosaceae)	seed	15	3.6			15	3.7	6	3.5	14	0.7
Pyracantha sp. (Rosaceae)	endocarp	10	2.4	58	11.9	18	4.5			6	0.3
Rosa sp. (Rosaceae)	endocarp					1	0.3				
Rubus sp. (Rosaceae)	endocarp	100	24.2	78	16.0	71	17.7	13	7.6	72	3.7
Oxalis sp. (Oxalidaceae)	seed	27	6.5	3	0.6	5	1.3	1	0.6		
Acalypha sp. (Euphorbiaceae)	seed	2	0.5	4	0.8	3	0.7				
Euphorbia sp. (Euphorbiaceae)	seed	7	1.7	6	1.2	2	0.5			3	0.2
Mallotus sp. (Euphorbiaceae)	seed			1	0.2	1	0.3	1	0.6		
Mercurialis sp. (Euphorbiaceae)	seed									1	0.05
Zanthoxylum sp. (Rutaceae)	seed	1	0.2	3	0.6					1	0.05
Meliosma sp. (Sabiaceae)	endocarp	2	0.5	4	0.8			1	0.6	1	0.05
Sabia sp. (Sabiaceae)	endocarp			1	0.2					2	0.1
Berchemia sp. (Rhamnaceae)	endocarp			1	0.2					6	0.3
Zizyphus sp. (Rhamnaceae)	endocarp			2	0.4						
Vitis sp. (Vitaceae)	seed			3	0.6						
Viola sp. (Violaceae)	seed	9	2.2	16	3.3			3	1.7	2	0.1
Myriophyllum sp. (Haloragaceae)	endocarp									2	0.1
Cornus sp. (Cornaceae)	endocarp									1	0.05

Taxa with their families	Part	Plant macrofossil assemblage zones									
		BG 1		BG 1		BG 1		BG 1		BG 1	
		total sum	(%)	total sum	(%)	total sum	(%)	total sum	(%)	total sum	(%)
Oenanthe sp. (Umbelliferae)	fruit	5	1.2	1	0.2	4	1.0				
Lysimachia sp. (Primulaceae)	seed							1	0.6		
Symplocos sp. (Symplocaceae)	endocarp	1	0.2	4	0.8	3	0.7			1	0.05
Verbena sp. (Verbenaceae)	seed	14	3.4								
Ajuga sp. (Labiatae)	fruit			1	0.2					1	0.05
Clinopodium sp. (Labiatae)	fruit	6	1.4	2	0.4	4	1.0	1	0.6	1	0.05
Elsholtzia sp. (Labiatae)	fruit					1	0.2				
Mosla sp. (Labiatae)	fruit	1	0.2	6	1.2	8	2.0				
Perilla sp. (Labiatae)	fruit	3	0.7								
Labiatae gen. et sp. indet.	fruit									13	0.7
Solanum sp. (Solanceae)	seed	3	0.7								
Sambucus sp. (Caprifoliaceae)	endocarp									2	0.1
Viburnum sp. (Caprifoliaceae)	endocarp	3	0.7	7	1.4	1	0.3			5	0.3
Sigesbeckia sp. (Compositae)	fruit	1	0.2								
Angiospermae-Monocotyledonae											
Nymphoides indica (Gentianaceae)	seed	8	1.9	1	0.2	82	20.5	2	1.2	1	0.05
Potamogeton sp. (Potamogetonaceae)	endocarp			1	0.2	5	1.3			6	0.3
Murdannia sp. (Commelinaceae)	seed					1	0.3				
Eleusine indica (L.) Gaertn. (Gramineae)	seed	2	0.5							1	0.05
Setaria viridis (L.) Beauv. (Gramineae)	fruit					1	0.3				
Sparganium sp. (Typhaceae)	endocarp							1	0.6		
Carex sp. (Cyperaceae)	fruit	13	3.1	35	7.2	55	13.7	18	10.5	67	3.4
Carex sp. *Carex* sect.(Cyperaceae)	c-fruit			1	0.2						
Schoenoplectus sp. (Cyperaceae)	fruit	82	19.8	6	1.2	5	1.3	12	7.0		
Unknown A	seed	6	1.4	15	3.1	13	3.2	4	2.3		
Unknown B	seed					1	0.3				
Unknown C	seed									6	0.3
Total count		415		486		406		172		1948	

the major angiosperm taxa of the warm temperate zone. *Pyracantha* and *Rubus* are the other common taxa. The subtropical elements *Eurya* and *Zizyphus* are also present in trace amount. The gymnosperms are totally absent. The dominance of warm climatic vegetation, appearance of subtropical taxa such as *Eurya* and *Zizyphus* and the complete absence of gymnosperms reveal the climate to be warmer than that of the underlying previous zone. Hence, it is concluded that this macrofossil zone was deposited during a warm temperate phase.

There are slight changes in the composition of taxa in the fossil assemblage zone BG-3. The warm temperate taxa such as *Carpinus*, *Pyracantha* and *Quercus* subgen. *Cyclobalanopsis* decreases and the subtropical element such as *Eurya* increases. The gymnosperms are still absent. Increase of aquatic taxa like *Nymphoides indica* and marshy taxa like *Carex* and *Schoenoplectus* indicate also strongly increasing humidity in this zone. From the above information, it may be concluded that this zone was deposited in warm temperate to subtropical humid phase.

The macrofossil assemblage zone, BG-4 is completely different than the previous zones. The gymnosperm taxon (*Abies*) reappears and abruptly increases to about 35% and also *Tsuga dumosa* to about 2%. The angiosperm trees are almost absent with few representation of *Carpinus*. *Eurya* (14%) is the only subtropical element in this zone. The herbaceous taxa are poorly represented. The humid phase is still documented in this zone as well with the findings of *Selaginella remotifolia*. Almost dominance of *Abies* and representation of *Eurya* reveals that there was fluctuation of climate from subtropical to cold temperate conditions during the deposition of this zone.

The gymnosperms which increased in the previous zone abruptly rose to their maximum in the macrofossil zone BG-5. The total sum of conifers (*Pinus*, *Picea smihtiana*, *Abies*, *Tsuga dumosa* and *Taxus wallichiana*) represented about 82% in the total count. The woody angiosperms are represented in very few amounts. The subtropical element *Eurya* is totally absent and also the herbaceous taxa are represented in much more high amount. So, the dominance

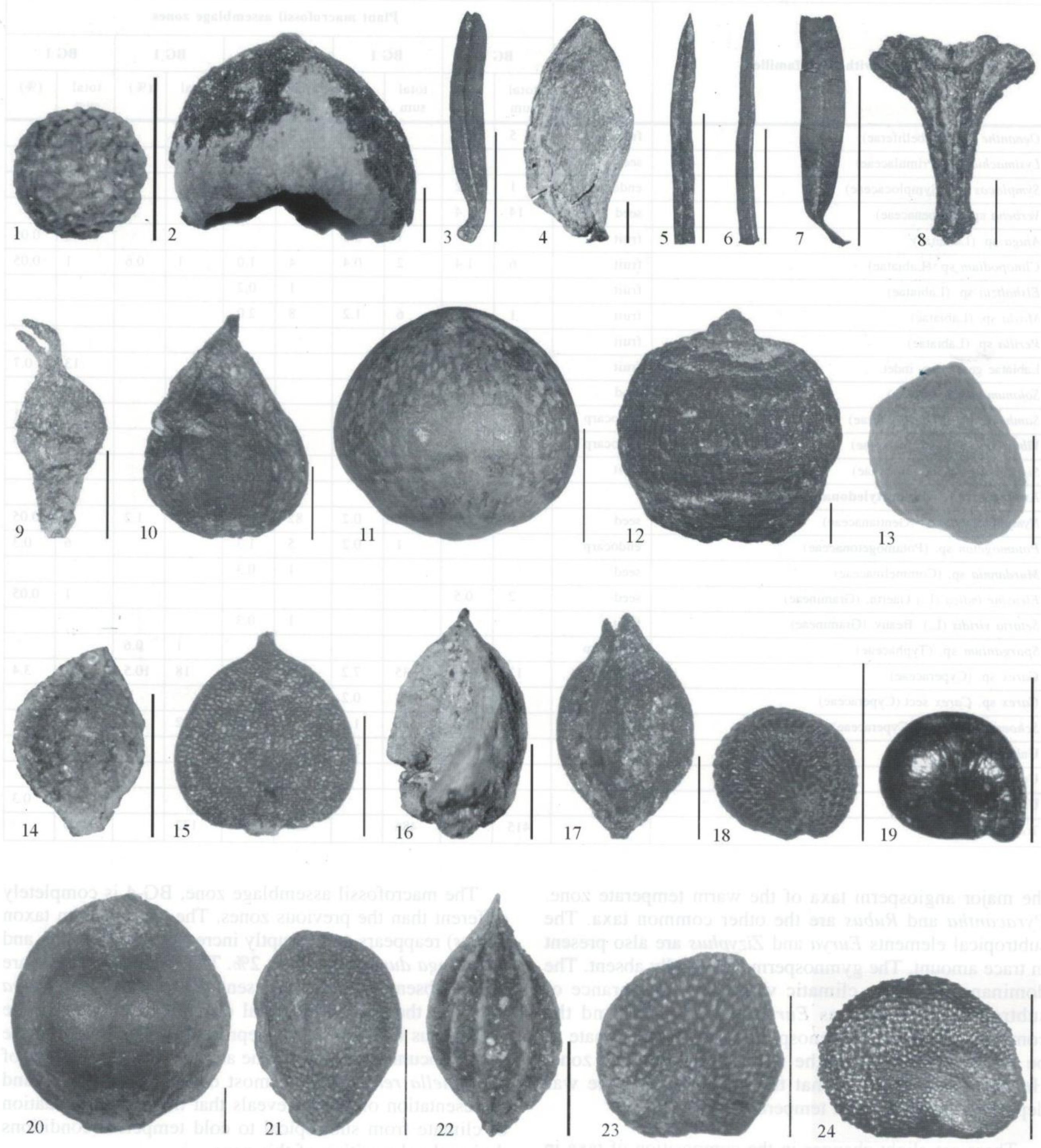

Fig. 5: 1. *Selaginella remotifolia* (macrospore), 2. *Taxus wallichiana* (seed), 3. *Abies* sp. (leaf), 4. *Abies* sp. (seed), 5. *Picea smithiana* (leaf), 6. *Pinus* sp. (needle), 7. *Tsuga dumosa* (leaf), 8. *Alnus* sp. (fruiting scale), 9. *Alnus* sp. (nutlet), 10. *Carpinus* sp. (nutlet), 11. *Corylus ferox* (nut), 12. *Quercus* subgen. *Cyclobalanopsis* (fruit), 13. *Morus* sp. (endocarp), 14. *Boehmeria* sp. (fruit), 15. *Persicaria nepalensis* (fruit), 16. *Persicaria thunbergii* (fruit), 17. *Polygonum* sp. (fruit), 18. *Stellaria* sp. (seed), 19. *Chenopodium album* (seed), 20. *Lindera* sp. (endocarp), 21. *Ranunculus* sp. (fruit), 22. *Thalictrum* sp. (fruit), 23. *Eurya* sp. (seed), and 24. *Corydalis pallida* (seed)

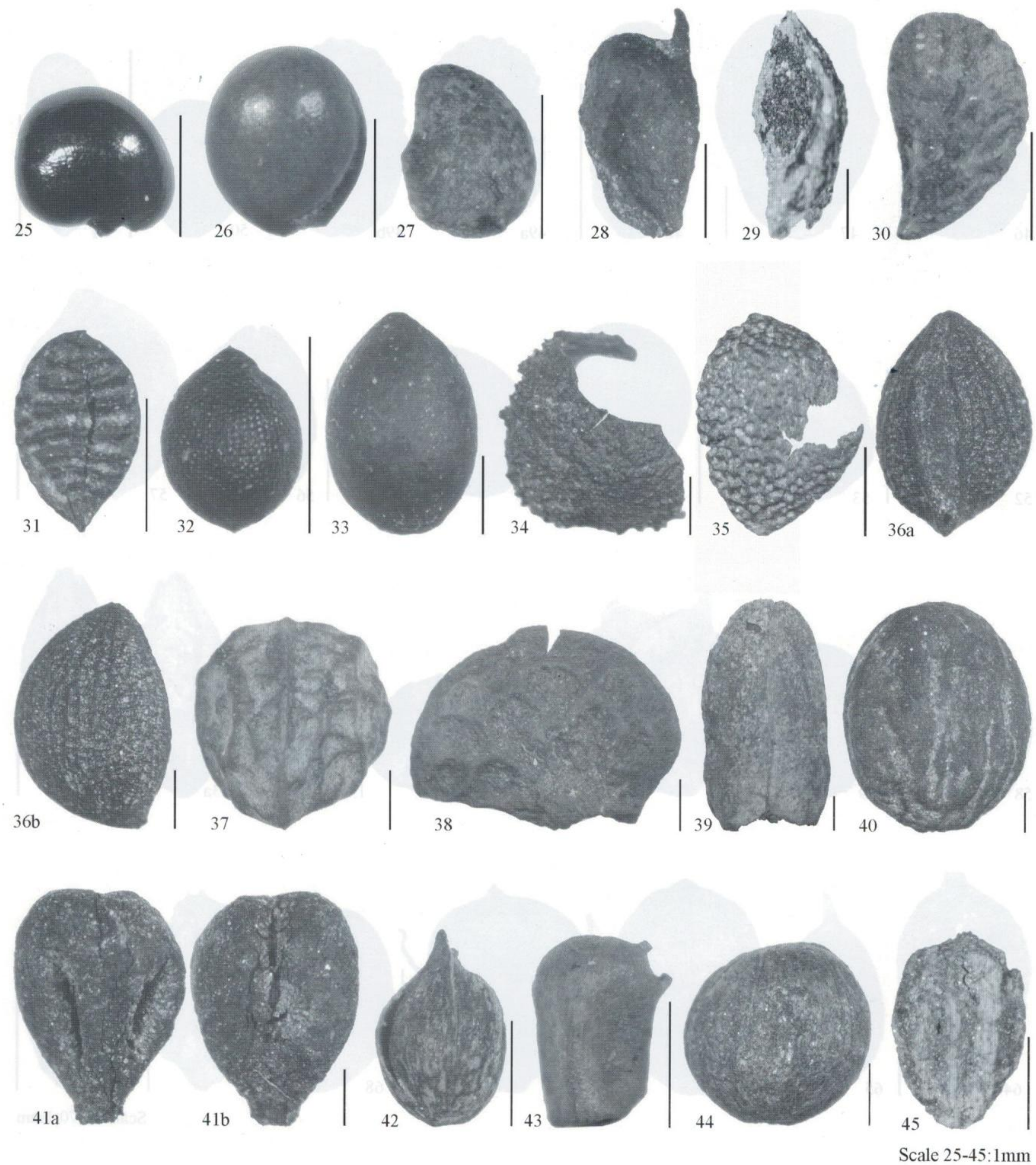

Fig. 6: 25. ***Corydalis*** **sp. (seed), 26.** ***Neillia*** **sp. (endocarp), 27.** ***Potentilla*** **sp. (fruit), 28.** ***Pyracantha*** **sp. (endocarp), 29.** ***Rosa*** **sp. (endocarp), 30.** ***Rubus*** **sp. (endocarp), 31.** ***Oxalis*** **sp. (seed), 32.** ***Acalypha*** **sp. (seed,) 33.** ***Euphorbia*** **sp. (seed), 34.** ***Mallotus philippenensis*** **(seed), 35.** ***Mercurialis*** **sp. (seed), 36.** ***Zanthoxylum*** **sp. (seed), 37.** ***Meliosma*** **sp. (endocarp), 38.** ***Sabia*** **sp. (endocarp), 39.** ***Berchemia*** **sp. (Endocarp), 40.** ***Zizyphus*** **sp. (endocarp), 41.** ***Vitis*** **sp. (seed), 42.** ***Viola*** **sp. (seed), 43.** ***Myriophyllum*** **sp. (endocarp), 44.** ***Cornus*** **sp. (endocarp), and 45.** ***Oenanthe*** **sp. (fruit)**

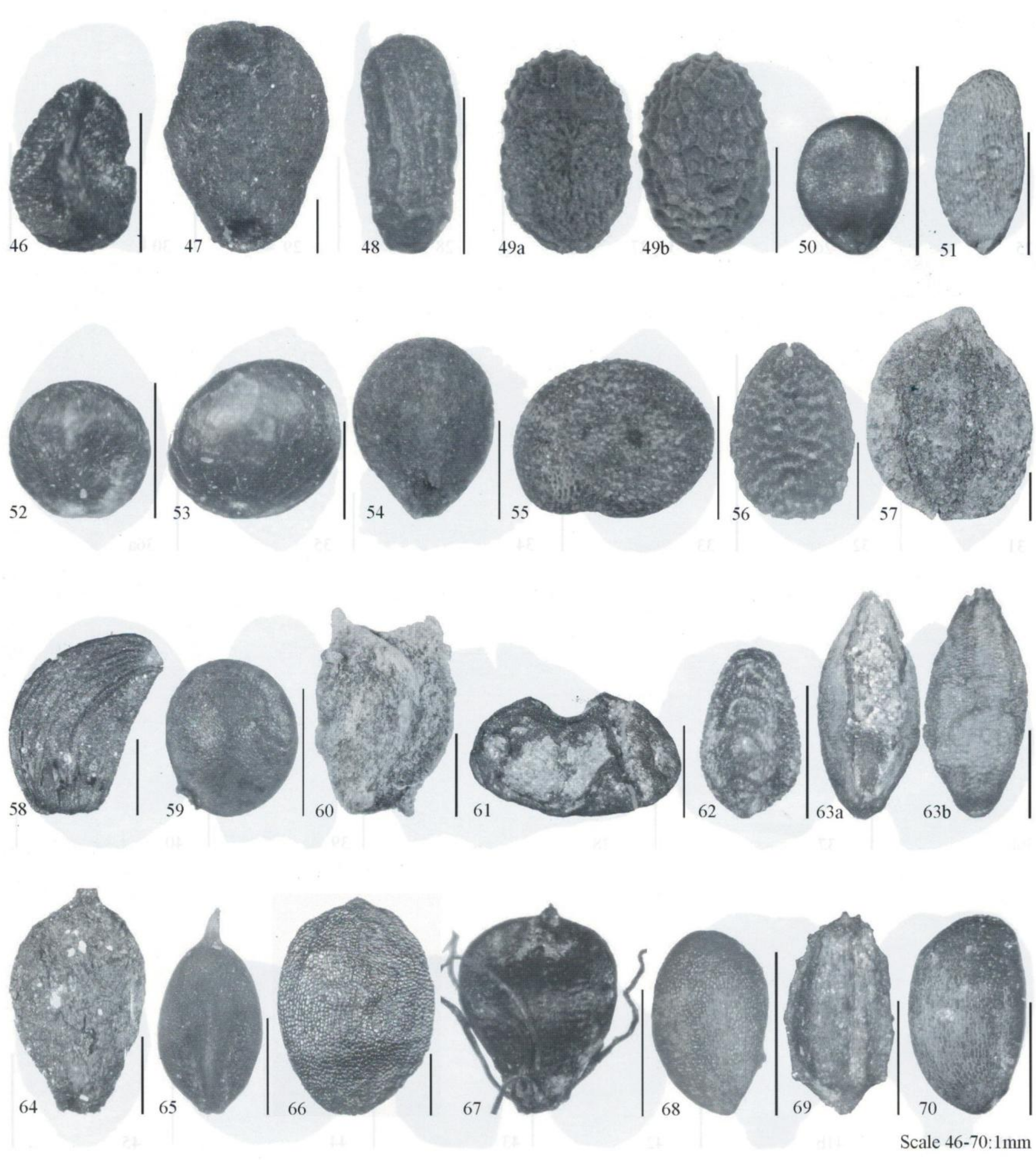

Fig. 7: 46. *Lysimachia* sp. (seed,) 47. *Symplocos* sp. (endocarp), 48. *Verbena* sp. (seed), 49. *Ajuga* sp. (fruit), 50. *Clinopodium* sp. (fruit,) 51. *Elsholtzia* sp. (fruit), 52. *Mosla* sp. (fruit), 53. *Perilla* sp. (fruit), 54. Labiatae (fruit), 55. *Solanum* sp. (seed), 56. *Sambucus* sp. (endocarp), 57. *Viburnum* sp. (endocarp), 58. *Sigesbeckia* sp. (fruit), 59. *Nymphoides indica* (seed), 60. *Potamogeton* sp. (endocarp), 61. *Murdannia* sp. (seed), 62. *Eleusine* sp. (seed), 63. *Setaria viridis* (fruit), 64. *Sparganium* sp. (endocarp), 65. *Carex* sp. (fruit), 66. *Carex* sp. *Carex* sect. (c-fruit), 67. *Schoenoplectus* sp. (fruit), 68. Unknown A (seed), 69. Unknown B (seed), and 70. Unknown C (seed)

of conifers clearly indicated a cooler climate during the deposition of this macrofossil zone.

Comparing the results obtained from the Besigaon section with that of Dhapasi section, Kathmandu Valley a drastic difference in the composition of plant macrofossil assemblages was found. The gymnosperm taxa (*Abies* and *Tsuga dumosa*) were very few in Dhapasi section (Bhandari et al. 2009) but here in Besigaon section the upper horizons contained 50-84% of conifers in the total count. The subtropical element likes *Eurya* and *Zizyphus* were abundant in Dhapasi section but very few in Besigaon section. In overall, Dhapasi section revealed subtropical to warm temperate climate whereas with the abundant presence of *Pyracantha*, *Carpinus* and *Quercus* in the lower horizons and dominance of gymnosperms (*Abies*, *Pinus*, *Picea*, *Tsuga* and *Taxus*) in the upper horizons resulted the climate to have changed from warm temperate to cold temperate during the deposition of this formation in the northeastern part of the valley. The present vegetation of the valley floor is characterized by *Schima-Castanopsis* forest of the subtropical region but the results obtained from plant macrofossil analysis do not contain such subtropical element with only the exception of *Eurya* in minor amount. The mountain slopes of the valley are mainly represented by the Oak forest and the top of the mountains surrounding the valley are very rarely represented by conifers at present. But the macrofossil analysis from the upper horizons shows a raising percentage of conifers, up to 82%, which strongly suggests climatic conditions much cooler than the present time. The macrofossil results tentatively support the pollen results from around these areas obtained by Nakagawa et al. (1996). The pollen results showed that the cold climatic evergreen taxa such as *Pinus wallichiana*, *Quercus semecarpifolia* and *Quercus lanuginosa* was dominated over warm climatic taxa such as *Pinus roxburghii* and *Quercus glauca*. Allowing the temperature lapse rate in the Himalayan area to be 0.6^0 C/ 100m (Ohsawa et al. 1983, Nakagawa et al. 1996), calculated the lowering of the mean temperature of the Kathmandu Valley by 6-7^0 C during the Late Pleistocene.

CONCLUSIONS

Plant macrofossils have been identified from the different plant macrofossil horizons of the Besigaon section of the Gokarna Formation. In total, 66 taxa belonging to 38 families were identified to the genus and species level. The characteristic feature of the Besigaon section is the dominance of angiosperms in the lower part and gymnosperms in the upper part. The dominance of warm climate indicators such as *Carpinus*, *Pyracantha*, *Quercus* subgen. *Cyclobalanopsis*, *Eurya* and *Zizyphus* revealed that the lower and middle part was deposited in a warm temperate climatic phase, whereas the reappearence and dominance over angiosperms of cool climate gymnosperms (*Abies*, *Pinus*, *Picea*, *Taxus wallichiana* and *Tsuga dumosa*) in the upper part of the section provided good evidence of a climate fluctuation during this depositional phase. The decrease in the subtropical and warm temperate elements and dominance of gymnosperms revealed that the upper horizons were deposited in cold temperate phase. Comparing the plant macrofossil results from this section to that of Dhapasi section, we concluded that the Besigaon section was deposited in much colder phase than that of the Dhapasi section. The detail study of the plant macrofossils from this exposure revealed that there was fluctuation of climate from warm temperate to extreme cold temperate phase during the deposition of the Gokarna Formation in the north eastern part of the Kathmandu Valley.

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