FOSSIL GASTROPODS FROM THE INDIAN UPPER SIWALIKS AND THEIR STABLE CARBON AND OXYGEN ISOTOPE VALUES INDICATE PRESENCE OF COLD CLIMATIC CONDITIONS IN THE EARLY PLEISTOCENE.

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The Early Pleistocene in general is characterized by widespread glaciations in the Northern Hemisphere. Early to Middle Pleistocene freshwater Pinjor Formation (Upper Siwalik) exposed all along the Himalayan Foot hills preserves a diverse faunal and floral assemblage. We carried out paleontological (gastropods) and stable isotope (carbon and oxygen isotope) studies of a 6 m thick swamp/pond deposit (that represents ~12,000 yrs) of Pinjor Formation, exposed near the Village Nadah, Panchkula (Haryana) and dated to ~1.8 Ma (Azzaroli and Napoleon,1982). We have identified four gastropod species in the assemblage, *Lymnae* sp., *Gyraulus sp.,Viviparous bengalensis* and *Hippeutis complantus.* The first two are widespread throughout the globe. *Lymnae* can exist in temperature range of 19° to 24° C and occur in Palearctic and Neoartic regions (animalbase.org). *Gyraulus* occur in Holoarctic region with temperature ranging from 17.8° to 30 °C (animalbase.org, theaquariumwiki.com), whereas Viviparous bengalensis typically exists in the Oriental region suggesting an overall warm and humid condition (Moore et al.,1997). *Hippeutis complantus* on the other hand exists in palearctic regions upto 63° N (Aplinarska and Cisewka 2006) under cold (6°to 23.3°C) and dry climatic conditions (Spyra., 2014).The powdered gastropod shell samples were analyzed using Continues Flow Isotope Ratio Mass Spectrometer (CF-IRMS) at the Wadia Institute of Himalayan Geology, Dehradun, India. The δ13C values of gastropod shells fall between -2.56‰ and 6.14‰ VPDB and suggest the dominance of C4 vegetation. The δ18O value of gastropod shell fall between -0.64‰ and -7.80‰ VPDB, suggesting fluctuation of climate between warm and cold conditions. Presence of *Hippeutis complantus* may suggest the extension of palearctic region up to Panchkula (Haryana, India) in the Early Pleistocene which presently lies in the Oriental Province. Therefore, our results indicate that the overall climatic condition during ~12000 years in the Early Pleistocene were warm and humid with some excursion towards cold and dry conditions for short time spans, supported by the occurrence of Palearctic gastropod *Hippeutis complantus* and δ18O values (-0.64‰ VPDB) .

INTRODUCTION

Siwaliks are freshwater deposits having thickness of almost 6000 meters. These sediments are exposed along the Himalayan foothills and are famous for mammalian fossils ranging in age from ~18 Ma (Johnson et al., 1985) to ~0.22 Ma (Rangarao et al., 1988) Fig.1. They have been classified as Lower, Middle and Upper Siwaliks, by Medlicott (1879) followed by Pilgrim (1910, 1913) who further divided them as Kamlial, Chinji, Nagri, Dhok Pathan, Tatrot, Pinjor and Boulder Conglomerate Formations, based on their faunal content Fig. 2. Palaeoclimatological and palaeoecological reconstruction of Siwaliks has been done by earlier workers between 18 to 5 Ma(Barry et al., 2002; Badgley et al., 2008). However preliminary works has been done so far between 6 to 0.02 Ma, which suggest that there was less rainfall i.e. decrease in monsoon intensity, more aridity and expansion of C_4 plants (Barry et al., 2002; Badgley et al., 2008). The actual trend of climate change, expansion of C4 and seasonality in monsoon pattern is still a mystery with respect to age at higher time resolution. The present study uses pedogenic clay nodules from paleosols and fossil gastropod shells as proxies to unravel the palaeoclimate trends in the Early Pleistocene times.

GEOLOGICAL SETTING

Ghaggar river section is a continuous fossilferous section exposed near Panchkula, Haryana. Nadah section is exposed adjacent to Ghaggar section and age of studied section is around 1.8 M.a. Fig 4. The fossliferous sediments were deposited along the Ghaggar River on its bank between 2.6 Ma to 0.5 Ma, which is further divided into Tatrot (just the upper part), Pinjor, Lower Boulder, and Upper Boulder Formations. The cyclicity of sandstone, siltstone & mudstone is observed in Tatrot & Pinjor Formation whereas sandstone and mudstones are interbeded with conglomerate in other formations (Kumaravel et al., 2005).
About 380 m thick Pinjor Formation exposed along the Ghaggar River is mainly composed of pink color sandstones. According to Kumaravel et al (2005) this formation was deposited under a high gradient and low sinuosity conditions suggesting rapid deposition fig.4. Earlier workers also reported some fauna from this formation which include the rodents: *Dilatomy* sp.*, Talera pinjoricus, Mus linnaeusi;* proboscideans: *Stegodon insignis, Archidiskodon planifrons, Elephas hysudricus;* equid *Equus sivalensi* and *bovids, Leptobos and Bos* (Nanda 1978).

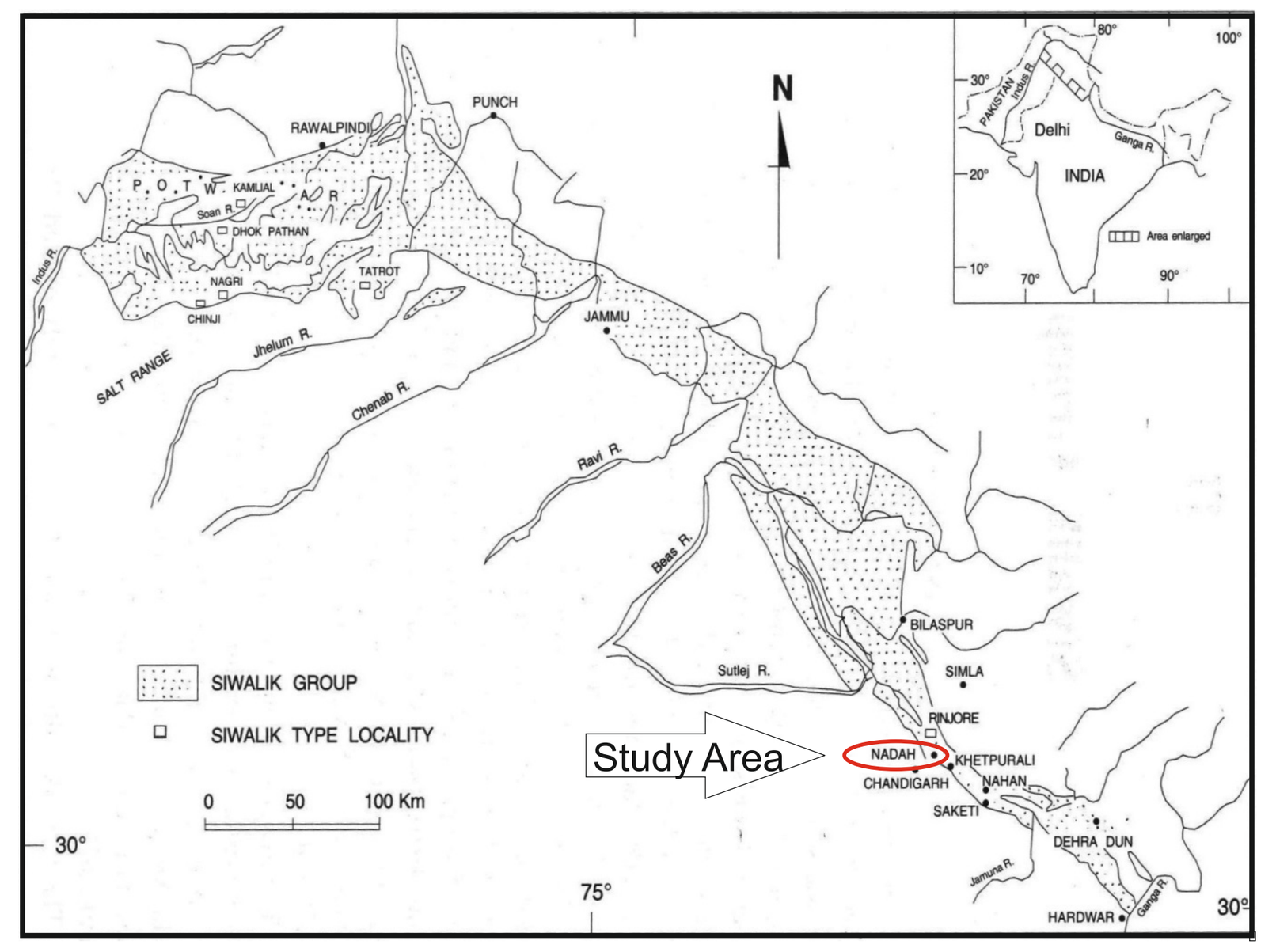


Fig.1. Siwalik belt of northwestern Himalaya showing important stratigraphic localities (Tandon,1991).

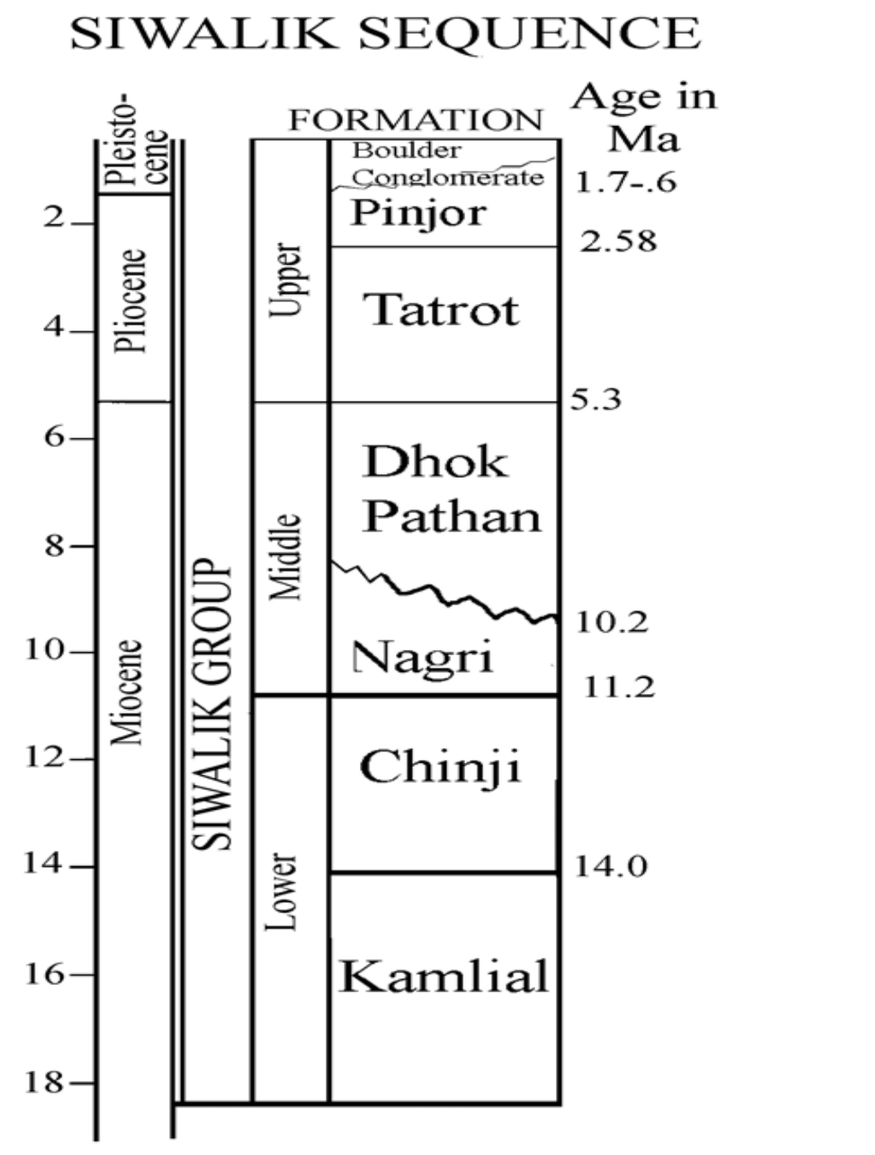
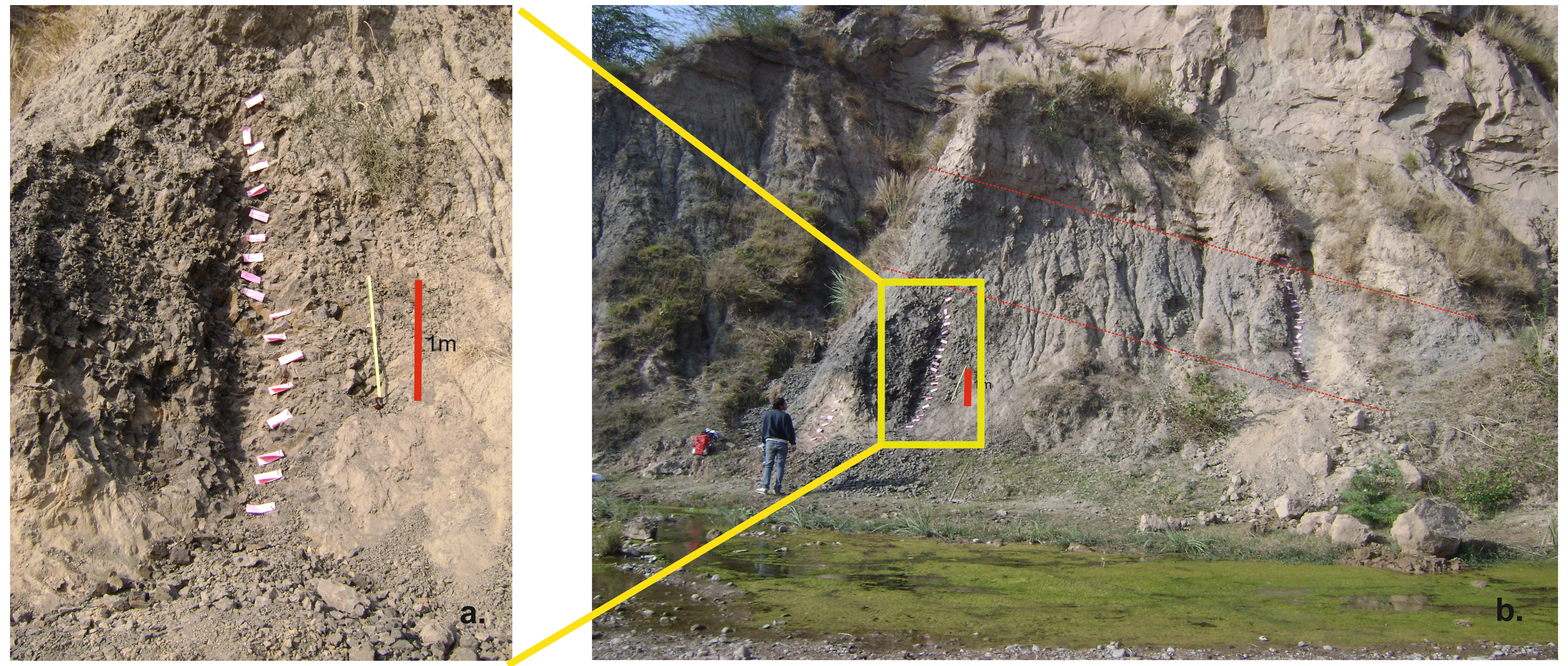


Fig.2. The Siwalik Stratigraphic Sequence (after Behrensmeyer and Barry 2005)

METHODOLOGY

The sediments containing gastropod shells and pedogenic nodules were collected at an interval of 15-17 cm as shown in fig.3a,3b and 6). The surface was dug about 25-30 cm to avoid any contamination (from the atmosphere gases and water) in the samples. The recovered small nodules are kept in small vials (0.5 ml) after testing with dilute HCL acid. About 400 –500 gm sediment samples were collected to recover nodules, and fossils shells on mega and microscopically.About 400 –500 gm sediment samples from each pont were collected to recover fossils shells and nodules on mega and microscopically. Complete and fragmented shells are recovered from the sediments after macerating the sediments in the laboratory. Complete shells are recovered under microscope and kept in diffrent glass slides. The complete shells were first identified under light microscope and then after photographed under Scanning Electron Microscope housed at Department of Geology, Panjab University, India. Shell fragments are then washed with distilled water many time (4-5 times) to remove any surficial contamination . The collected shells were rapped with WHATMAN filter paper separately from each point and kept at 35 - 40 °C in oven for overnight to dry. Than after recovered shells were crushed and made fine powder using agate pestle mortar, which further stored in air tight vials and the vials were kept in the vacuum desiccator. Now the sample are ready to be analysed under the IRMS technique to get δ^{13} carbon and δ^{18} oxygen stable isotopic data. IRMS (isotopic ratio mass spectrometer is the instrument that calculates the δ 13C/12 C ratio and δ 18 O/16 O ratio).The stable isotopic ratio of Carbon ($\delta^{13}C$) and Oxygen ($\delta^{18}O$) in nodules and shells were measured in stable isotope lab of WIHG using Gas Bench with CF–IRMS. In this process approximately 100 - 500 µg powdered nodule and shell samples are kept in individual 12 ml vials. These vials are placed in Gas Bench Tray at 72 °C for flush fill with 99.9995% pure Helium gas, to remove all atmospheric gasses from the vials. Further, 50–70 µL phosphoric acid (H3PO4; ≥99 % Crystalline) is poured in the vials, to produce CO2 gas (see eq 1). The CO2 gas produced in 45 minutes at 72 °C after acid dosing. Now, we can analyze the CO2 and get the isotopic ratio of Carbon (δ13C) and Oxygen (δ18O) using SSH correction given by Santrock et al., 1985. The Blank, In House Standard and International Standard (NBS-18) are also run with each set of batch for bracketing the samples. Precision of these measurements is ±0.1‰.



(Fig.3a and 3b).Field photographs showing the technique of sampling.

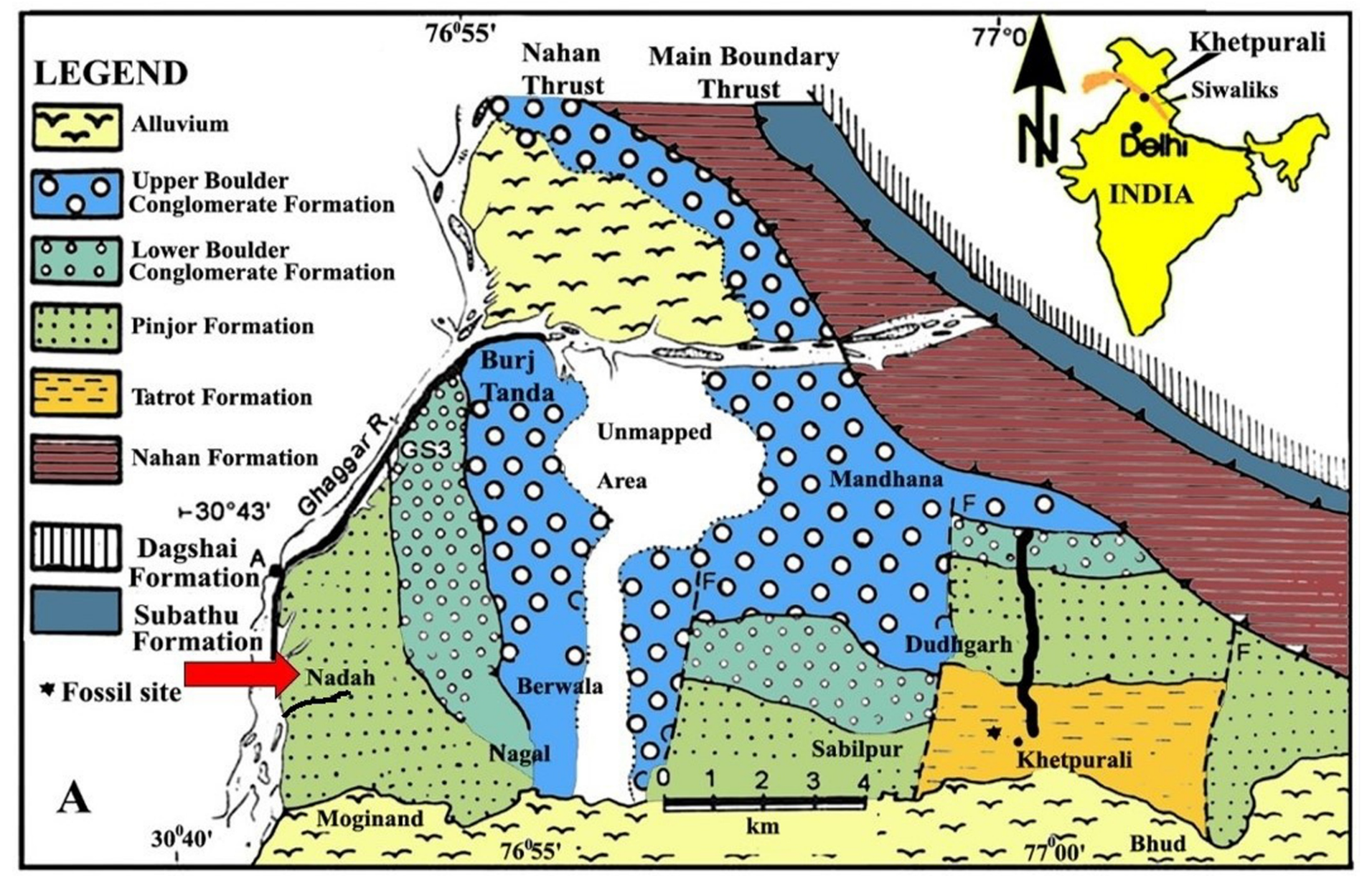

LEGEND
Alluvium
Upper Boulder Conglomerate Formation
Lower Boulder Conglomerate Formation
Pinjor Formation
Tatrot Formation
Nahan Formation
Dagshai Formation
Subathu Formation
Fossil site
76°55'
Nahan Thrust
Main Boundary Thrust
77°0'
N
Khetpurali
Siwaliks
Delhi
INDIA
Nadah
Khetpurali
A

Fig.2 Geology of the area exposed near Chandigarh, India, and area of research. The geological map is modified from Kumar and Tandon (1985).

DISCUSSION

Carbon isotope

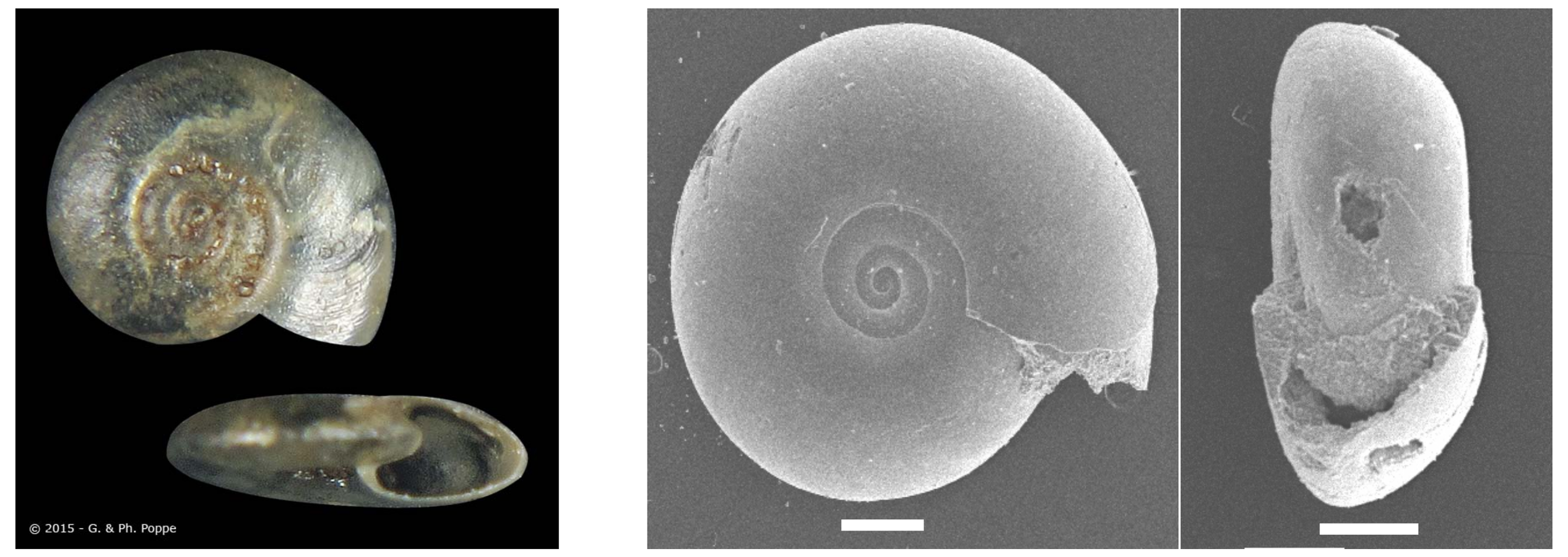
$\delta^{13}C$ values of gastropod shells have been widely used to reconstruct the palaeovegetation (Balakrishnan et al., 2005). There are generally three types of plants, C_3, CAM and C_4. All these plants have different pathways for photosynthesis and they use different enzymes in the process. That is why they have difference in efficiency to fix CO_2 at the same temperature which results is having different carbon ($\delta^{13}C$) values (Cerling and Quade, 1993). The process which fixes CO_2 by C_3 acids is called Calvin–Benson cycle and the process which fixes CO_2 by C_4 acids is known as Hatch–Slack cycle (Selagen et al., 2007). Crassulacean Acid Metabolism (CAM), the third pathway is generally a combination of Calvin–Benson and Hatch–Slack cycle pathways. The $\delta^{13}C$ values range from -22 to -38‰ for C_3 plants, whereas for the C_4 plants the value ranges from -9 to -21‰ (Raven et al., 1981; Salisbury and Ross, 1985; Biedenbender et al., 2004). The $\delta^{13}C$ isotopic values of gastropod shells also suggest C_4 vegetation as it falls in the range of -2.56‰ and 1.44‰ VPDB (Balakrishnan and Yapp, 2004). There is 14‰VPDB enrichment of $\delta^{13}C$ in shell and it is because of their metabolism (McConnaughey and Gillikin, 2008). C_4 plants are identified as dominant vegetation in one of the study carried by Balakrishnan and Yapp (2004) for $\delta^{13}C$ value of snail shell ranges from -4.3‰ to -1.9‰ and the overall average was -2.8‰. A vegetation with dominancy of C_3 plants should be depleted in $\delta^{13}C$ or we say it have more negative values of $\delta^{13}C$ (Balakrishnan and Yapp, 2004).(Fig.6a)

Oxygen Isotopes

Beside Carbon isotope (δ13C) values, the Oxygen isotope (δ18O) value of gastropod shells are used to reconstruct the palaeoclimate (Leng and Lewis, 2014). In general land gastropods are active only in temperature between 10°C to 27°C (Cowie, 1984; Thompson and Cheny, 1996). They are active only above the values of Relative Humidity (RH) that is 0.70 expressing RH as a decimal fraction (Van der Schalie and Getz, 1961, 1963). So, land snails are active only following rains or at nights (Cook, 1979). The gastropod shells can only be precipitated when snails are active (Cowie, 1984). Therefore, δ18O values of gastropod shells should reflect conditions within moderately narrow ranges. These ranges may vary from genus to genus as in this study. In general the occurrences of Lymnea, Gyrulus and Viviparus suggest the presence of warm and humid conditions. However, the existence of Palearctic species *Hippiteus* may suggest cold and dry condition in past time at ~1.8 Ma. The depleted values of δ18O in gastropods suggest cold and dry condition for small period of time (i.e. 30.36 ‰, 28.32 ‰, 28.17 ‰) whereas the rest of the values, lowest of which is 22 ‰ may suggest presence of warm and humid temperature.(Fig.6b)

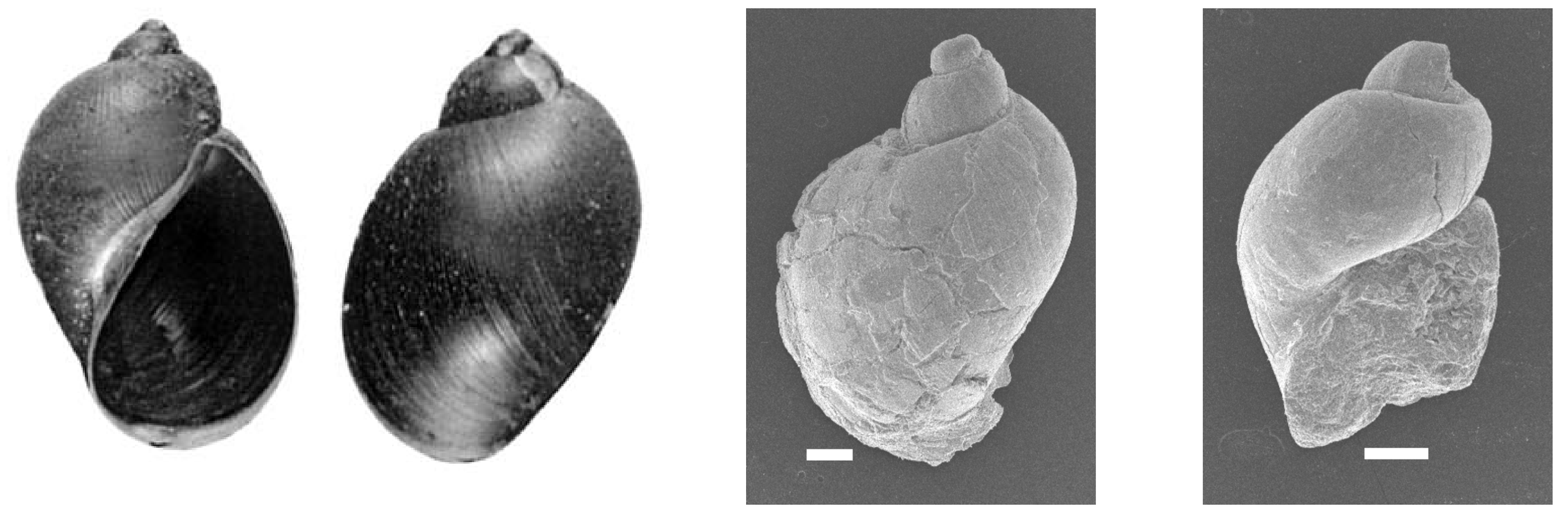
PRESENT DAY GASTROPODS

FOSSILISED GASTROPODS



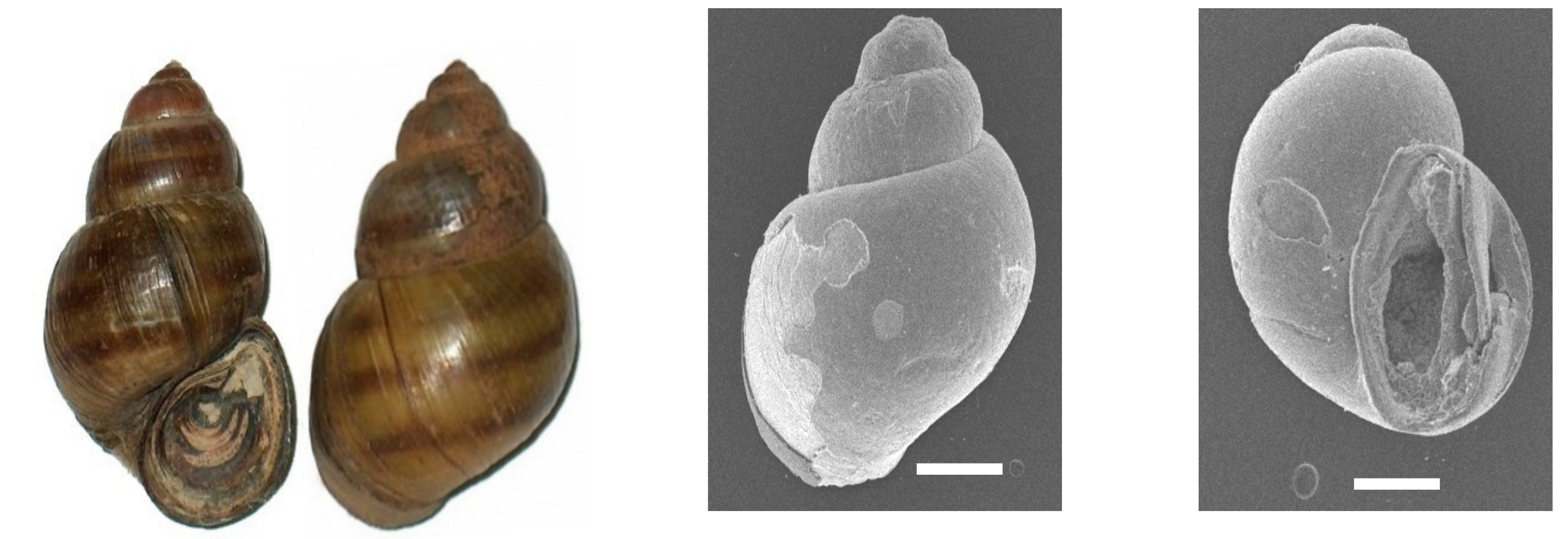
Hippeutis complanatus **(Bar Scale 500 µm)**

Present day distribution:- *H. complanatus* occur in Palearctic region up to - 63°N (Apolinarska and Ciszewzka, 2006) and ranges from NW-Africa, whole region of Europe to the Yenisei and Ob in Siberia. In the south, it ranges up to Caucasian countries and in the north up to Scandinavia. Recently in 2013 it was recovered from lake Bangong, Tibetan Plateau (Oheimb et al., 2013).
Ecology:- . *Hippeutis complanatus* (Linnaeus, 1758) occurs in stagnant waters lush with vegetation (Merkel, 1894; Boycott, 1936; Kerney, 1999) as well as in waters with a low speed of flowing. The temperature range for its existence is 6-23.3°C with an average of 14.5°C (Spyra, 2014). *H.complanatus* is a calciphilous species, lives in water with calcium content ranging between 19–34 mg/l, (Young, 1975; Økland, 1990; Kerne, 1999; Briers, 2003, Strzelec, 1993a, Lewin and Smoliński, 2006). *H. complanatus* survive in water with total hardness ranging from 0.9 to 1.7 °dH according to Aho (1966). The tolerance range of pH for the species in water is 6.1 to 7.5, (Spyra, 2014).



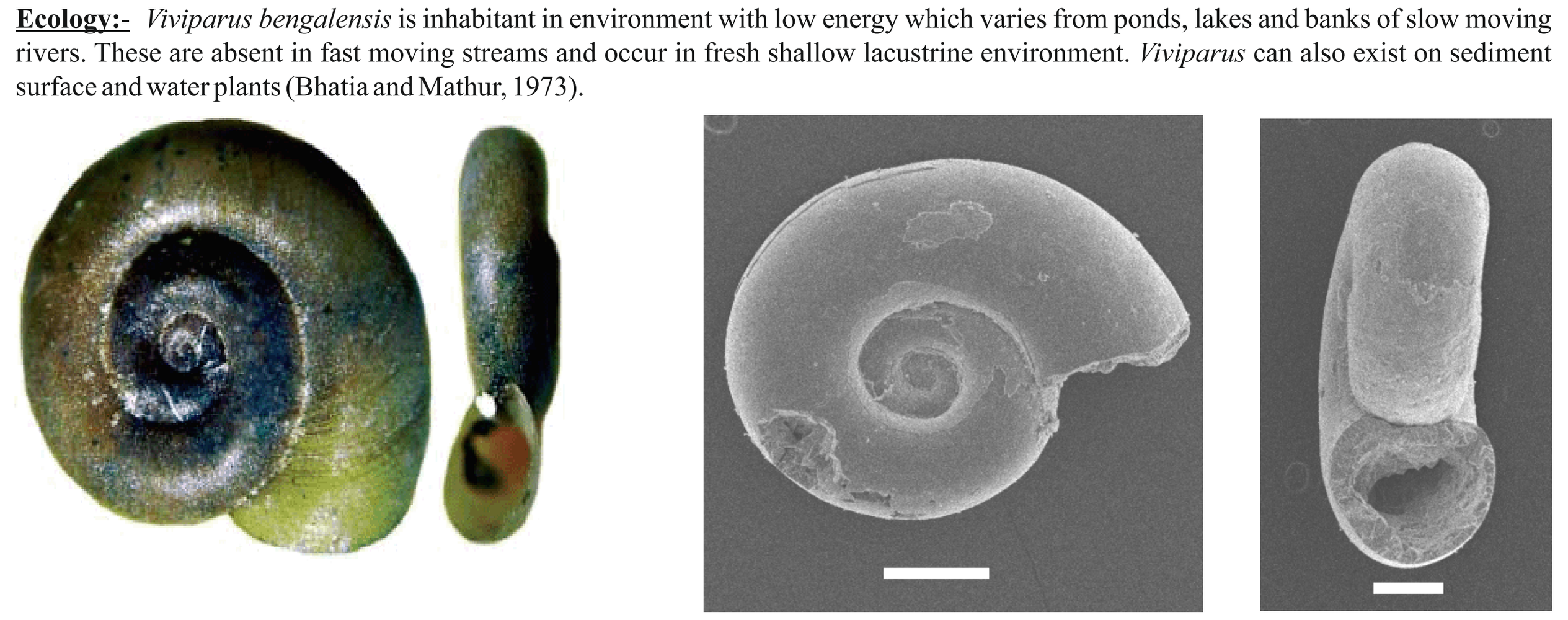
Lymnaea **sp. (Bar Scale 500 µm)**

Present day distribution: - It is widespread in Palearctic and Nearctic regions. It occur in North, South central and Southeast Asia. It is also distributed in North Africa, North America, New Zealand and in European Mediterranean countries (Liu et al., 1979)
Ecology:- This species inhabits standing or sluggish waters, they generally occur on the edges of streams, pools, reservoirs, amongst others. They like muddy sand or crushed stone bottom,and feed on aquatic plants, diatoms, and tissue remains of other gastropods. *Lymnaea* prefers shallow water and can survive in temperature range of 19°-24°C but they can tolerate high pH level (www.animalbase.uni-goettingen.de).



Viviparus bengalensis **(Bar Scale 500 µm)**

It is a widespread Indian gastropod species reported from Pinjor Formation of Upper Siwaliks exposed near Chandigarh by Bhatia and Mathur (1973).
Present day distribution: - It is an Oriental species (Moore et al., 1952) and exist in south Asia regions which include Bangladesh, Iran, Nepal, Myanmar, Pakistan, Sri-Lanka, and all over India (Budha et al., 2010).
Ecology:- *Viviparus bengalensis* is inhabitant in environment with low energy which varies from ponds, lakes and banks of slow moving rivers. These are absent in fast moving streams and occur in fresh shallow lacustrine environment. *Viviparus* can also exist on sediment surface and water plants (Bhatia and Mathur, 1973).



Gyraulus sp**.** cf to Gyraulus singularis **(Bar Scale 500 µm)**

Present day distribution:- It is a Holarctic species.
Ecology:- Gyraulus is epifaunal fresh water species so it can exist on the surface as well as at the bottoms of ponds, lakes and also open water channels with muddy bottoms (Annandale and Prashad, 1919; Prashad, 1937). It also lives on the surface of plants and rocks that are submerged beneath water surface. Their presence indicate fluvial and lacustrine facies (Bhatia and Mathur 1973). They are grazers in general and scrape biofilms from submerged surface. Gyraulus can survive in water with temperature ranging between 17.8° to 30° C, total water hardness between 8- 18d with pH ranging between 7.0 – 8.0. (theaquariumwiki.com)

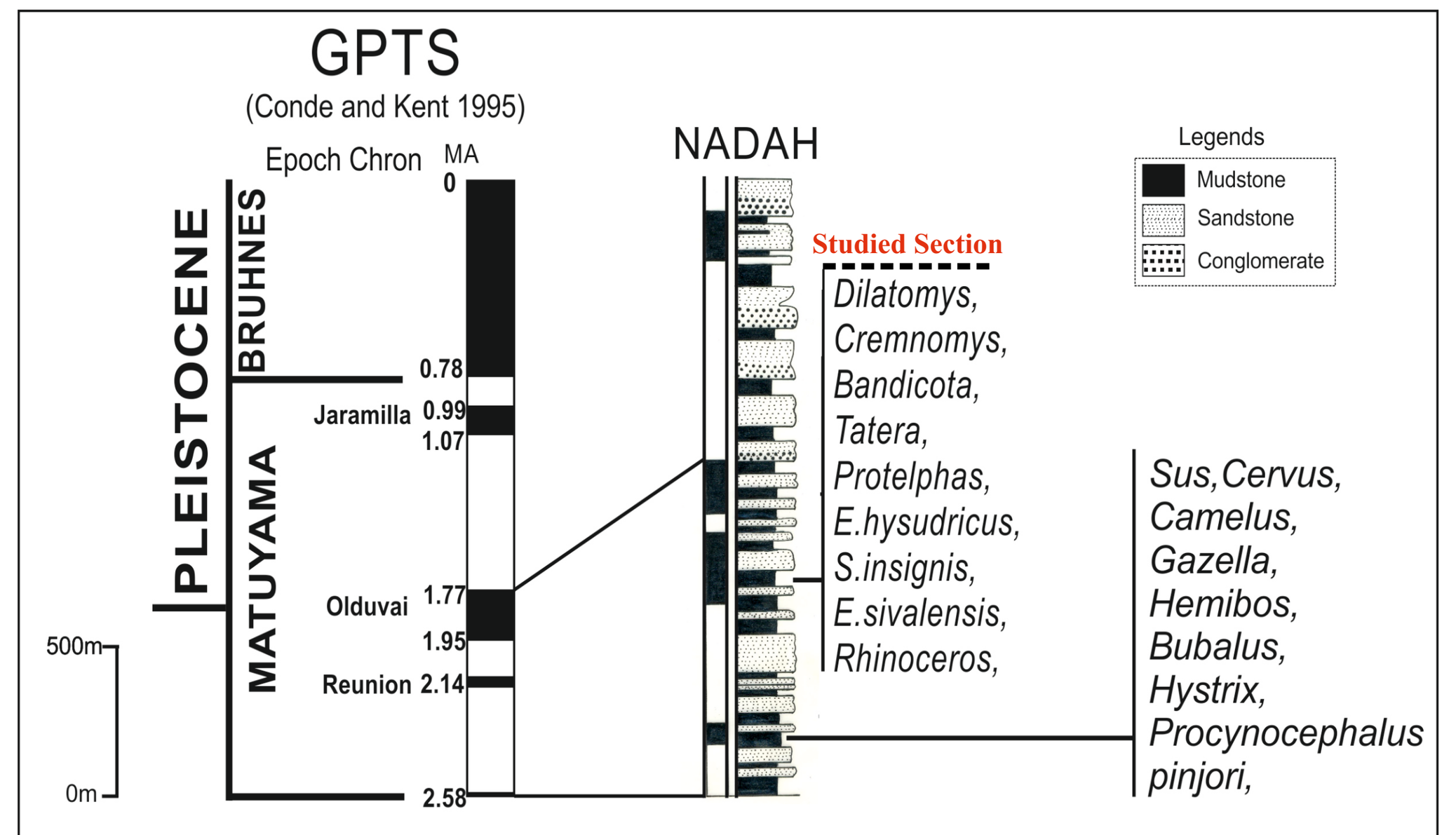

GPTS
(Conde and Kent 1995)
Epoch Chron
MA
PLEISTOCENE
BRUHNES
MATUYAMA
Jaramilla
Olduvai
Reunion
0.78
0.99
1.07
1.77
1.95
2.14
2.58
500m
0m
NADAH
Studied Section
Dilatomys,
Cremnomys,
Bandicota,
Tatera,
Protelphas,
E.hysudricus,
S.insignis,
E.sivalensis,
Rhinoceros,
Sus,Cervus,
Camelus,
Gazella,
Hemibos,
Bubalus,
Hystrix,
Procynocephalus
pinjori,
Legends
Mudstone
Sandstone
Conglomerate

Fig.4. Stratigraphic position of the present section in the overall paleomagnetically dated Nadah section. Source:- Azzorili and Napoleone (1982), Conde and Kent (1995) and Patnaik (2003).

RESULTS

The $\delta^{13}C$ values of gastropods shells ranges between -2.56‰ to 1.44‰ VPDB with enrichment of ~14‰ with an average $\delta^{13}C$ values of -0.6‰ VPDB ±2.0‰. Graphic representation is shown in fig.6a. The stable carbon isotopic value of gastropod shell suggest the dominance of C_4 vegetation in the Early Pleistocene. Where as the average $\delta^{18}O$ value shells is 24.4‰ VSMOW ±1.4‰ and ranges between 22.88 ‰ to 30.26 ‰ VSMOW as shown in fig.6b.

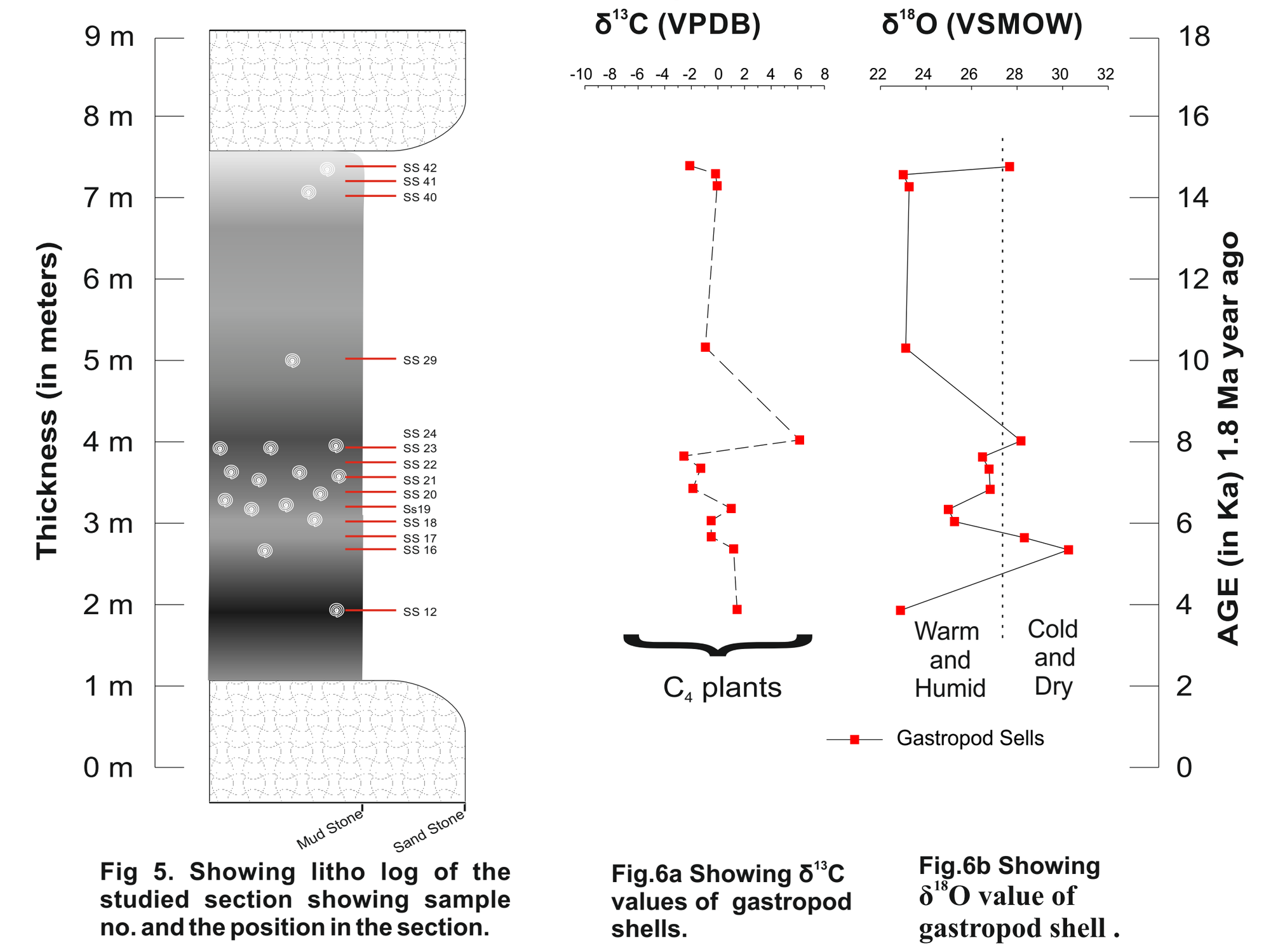


Fig 5. Showing litho log of the studied section showing sample no. and the position in the section.

Fig.6a Showing $\delta^{13}C$ values of gastropod shells.

Fig.6b Showing $\delta^{18}O$ value of gastropod shell .

FLORA AND FAUNA REPORTED FROM NADAH SECTION

A basal Pinjor locality is exposed near village Nadah that has yielded a rich assemblage of micro and mega fossils. The microfossil assemblage from this site include rodents, *Mus* cf. *M. flynni*, *Golunda* sp., *Cremnomys* cf. *C. blanfordi*, *Bandicota* sp., cf. *Tatera* sp., *Crocidura* sp., and *Dilatomys* sp.; (Patnaik, 2003) ostracodes, *Hemicypris megalops*, *Ilyocypris bradyi*, *Strandesia indica*, *Zonocypris costata*, *Vergatocypris nadahensis* (Bhatia, 1996); the charophytes, *Chara globularis globularis, Chara globularis aspera, Lamprothamnium papulosum, Chara globularis aspera, Sphaerochara prolifera Lamprothamnium succinctum,* (Bhatia, 1999), *Viviparus, Gyraulus* (Gastropods) and *Pisidium* (Bivalve) and pollens and spores (Rao and Patnaik 2001). The pollen and spores have been further separated into three communities (i) Low-land elements (*Frasnacritetrus, Polyadosporites, Retitrescolpites, Malvacearumpollis and Graminidites);* (ii) Freshwater elements *(Zygnema, Spirogyra, Mougeotia, Pteridacidites, Striatriletes, Lycopodiumsporites, Jacobipollenites and Nymphaeacidites); and* (iii).Montane elements *(Cycadopites, Laricoidites, Inaperturopollenites, Podocarpidites, Pinuspollenites, Abiespollenites* and *Piceapollenites)*. Whereas, the megafossils includes: *Sus, Cervus, Camelus, Gazella, Hemibos, Bubalus, Hystrix, Procynocephalus pinjori.*

CONCLUSION

In general the Early Pleistocene of the Northern Hemisphere is characterized by widespread glaciations. Till date there was no clear evidence for cold conditions in the Early Pleistocene of Pinjor Formation which is exposed along the Himalayan foothills. Carbon (δ13C) and Oxygen (δ18O) isotope values from gastropod shells from a 6 m thick swamp deposit belonging to the basal Pinjor Formation were studied in order to reconstruct the palaeoclimate and palaeovegetation. Although δ13C and δ18O values when plotted on the graph (Fig.4). δ13C values from gastropod shells clearly indicate the dominance of C4 vegetation in the area in the Early Pleistocene. δ18O values , in general, suggests presence of warm and humid climate interspersed with cold and dry conditions during this ~12,000 years. Four genera of gastropods recovered from the section also support the interpretation based on isotopic studies. One (*Hippeutis complanatus*) of the gastropod genera recovered from the section indicate presence of cold and dry climate as it is primarily a Palearctic species and exist only at places where the average temperature is around 14.5 °C. It also suggests the extension of Palearctic Zone boundry upto Chandigarh(Fig.7) The other three genera *Lymnae* sp., *Gyraulus* sp., and *Viviparus* are common in the Oriental region and exist in a relatively warm and humid climate condition.

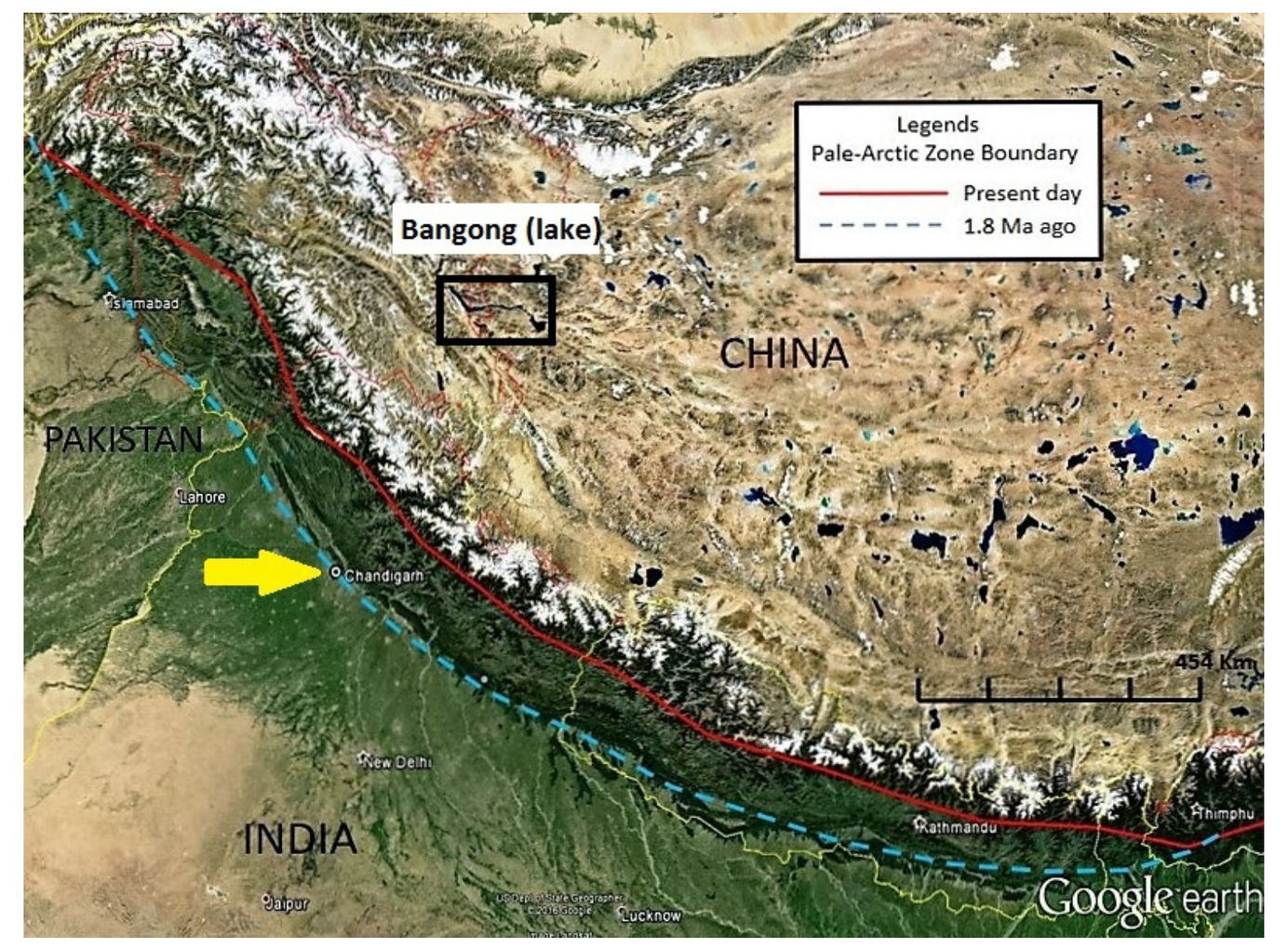


Fig.7. Showing the most probable boundary of pale arctic zone 1.8 Ma ago passing through Chandigarh. Map source ©Google 2016.

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