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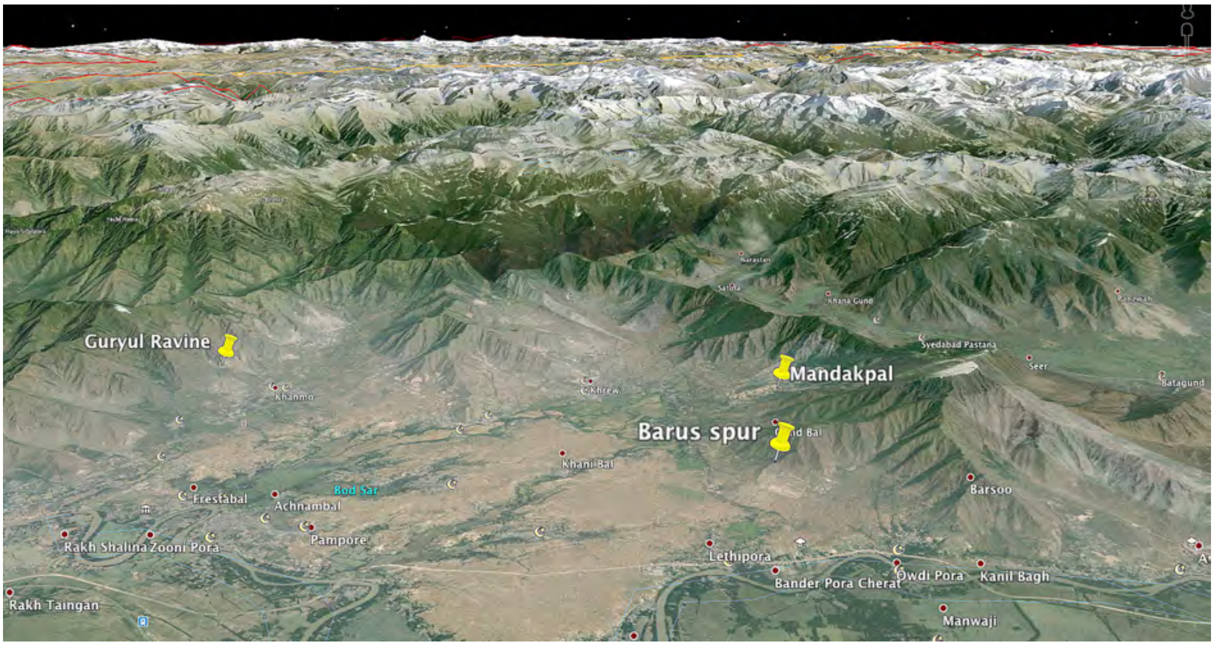
IGCP 630 Field Guide Book 1

The Permian-Triassic transition in the Kashmir Valley



IGCP 630 Field Workshop in Kashmir

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Corrected Web version according to some new data founded during the field workshop

IGCP 630 First Annual Field Workshop in North India

(17-22 November, 2014, Srinagar, India)

Conveners: Ghulam M. Bhat[1] & Zhong-Qiang Chen[2]
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Field workshop schedule:

November. 17, morning, arrival of the participant flying from Dehli.

November. 17 afternoon: conference and presentation of the sections.

November. 18: Guryul Ravine section, lower Part,; the Permian Zewan Formation from basal transgression above the Panjal trap up to the top of Member D with Brookfield's seismite and tsunamites.

November 19: Guryul Ravine section, upper Part, the Kunamuh Formation from Member E1, and E2 with the Permian Triassic boundary, members E3, F-G with the Induan –Olenekian boundary and H-I with the Smithian-Spathian Boundary and the upper seismite.

November 20: Mandakpal section with the brachiopod rich upper Permian Zewan Formation, The Permian-Triassic boundary seen in the slope and parts of members E, F, G in the upper quarry.
November 21: Barus section from top Zewan to E3

November 22: Samples packing for expedition, departure of the participants in the afternoon.

Scientific collaboration agreement between Switzerland and India

Dr. Nicolas Goudemand (Zurich University, Switzerland) has been in charge of a research project on Lower Triassic conodont biochronology including Kashmir. The Palaeontological Institute, University of Zurich, Switzerland, established with Professor G.M. Bhat, Head of the Department of Geology, University of Jammu, India a 2011-2013 collaborative programme in the field of Geosciences research.

Field researches on lower Triassic Kasmir sections has been undertaken in May 2012 with Professor G.M. Bhat, Dr. Nicolas Goudemand, Dr. Aymon Baud and a Ph. D. student Max Meier.

During October 2013, Professor G.M. Bhat, Dr. Aymon Baud, Morgane Brosse (Ph. D. student) and Marc Leu (Msc. student) resampled part of lower Triassic sections in Guryul Ravine area.

Only abstracts have been published (Brosse et al., 2013, Leu et al., 2014) and works are still in progress and cannot be included in this guide book.

Contents

Part A –Introduction to the Permian –Triassic of Kashmir

1- Prelude.

Stratigraphy of the Kashmir and the Himalaya has a long story. The first scheme was established by Lydekker (1883) who divided the Paleozoic rocks into the “Metamorphic”, Panjal and Zanskar systems.

Triassic stratigraphy of Himalayan Range was studied first by Griesbach (1880). During his Survey of the Central Himalaya, he discovered the *Otoceras* ammonoid and he was the first who understood the importance of this fossil to mark the base of the Triassic Series and the Permian-Triassic boundary. During the Year 1895 appears three masterly works

1-The Mojsisovics, Waagen and Diener (1985) paper with the Lower Triassic subdivision proposal made by Waagen and Diener. In their paper, they strongly advised the use of the *Otoceras* Beds described in the Central Himalaya to define the base of the Triassic.

2- In the same year, Wilhelm Waagen (1895) published an impressive paleontological work on the Salt Range fossils.

3- On the footsteps of C. Griesbach, Carl Diener explored the Central Himalaya and published his survey in 1895.

Following Wilhelm Waagen, Diener visited also the Salt Range, then the Permian-Triassic sections in Kashmir. He founded also *Otoceras* in Spiti sections and made comparisons with the Shalshal Cliff in the Central Himalaya (Diener, 1912). All these extensive paleontological collections have been carefully stored at the Geological Survey of India in Calcutta (Baud, in press).

In 1910, Charles Stewart Middlemiss described and illustrated in detail the stratigraphy and fossils of the Kashmir region (Fig. 1). He subdivided the Paleozoic rocks into litho- and chronostratigraphic units, with “Older Silurian”, “Upper Silurian”, Muth Quartzite, “Syringothyris Limestone”, Passage Beds, “Fenestella Series”, “Agglomeratic Slates”, “Panjal Volcanic Flow”, “Gangamopteris beds”, Zewan beds. The Triassic units are: the "Lower Triassic", the "Muschelkalk and the "Upper Triassic".

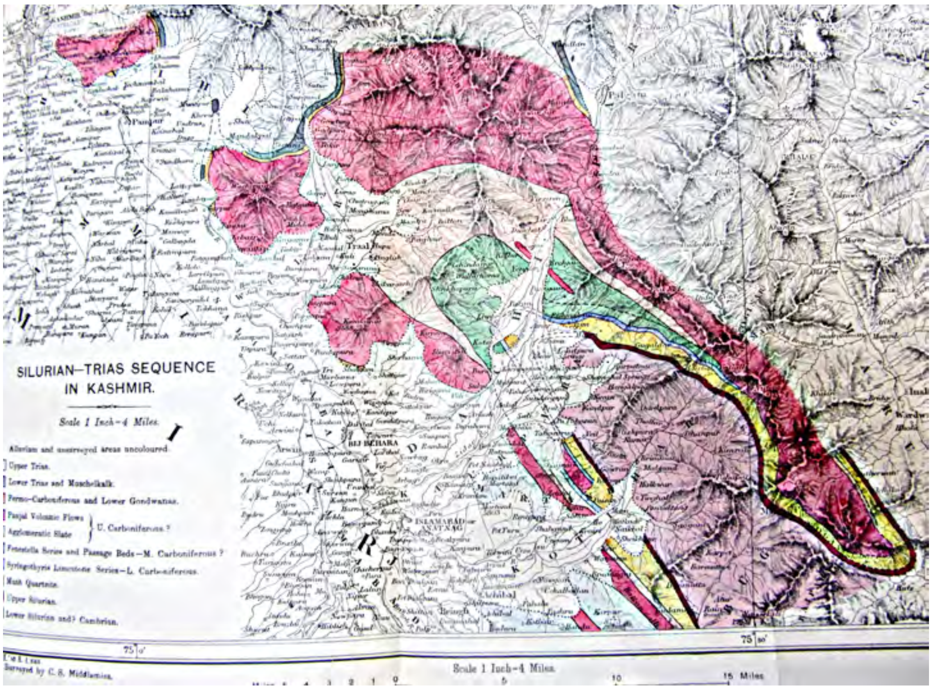


Figure 1: *Kashmir Geological map of C. S. Middlemiss. (1909)*

Wadia (1934) also described the general geology of Kashmir, but renewing interest to the Kashmir sections started in 1968 when Curt Teichert and Bernhard Kummel spend 2 days at the Guryul Ravine section, collected samples and wrote a paper (Teichert & Kummel, 1970), and the same year, W.C. Sweet gave an account on the conodont zonation from late Permian to early Triassic at Guryul Ravine (Sweet, 1970). Fig. 2 below is showing their new PTB interpretation.

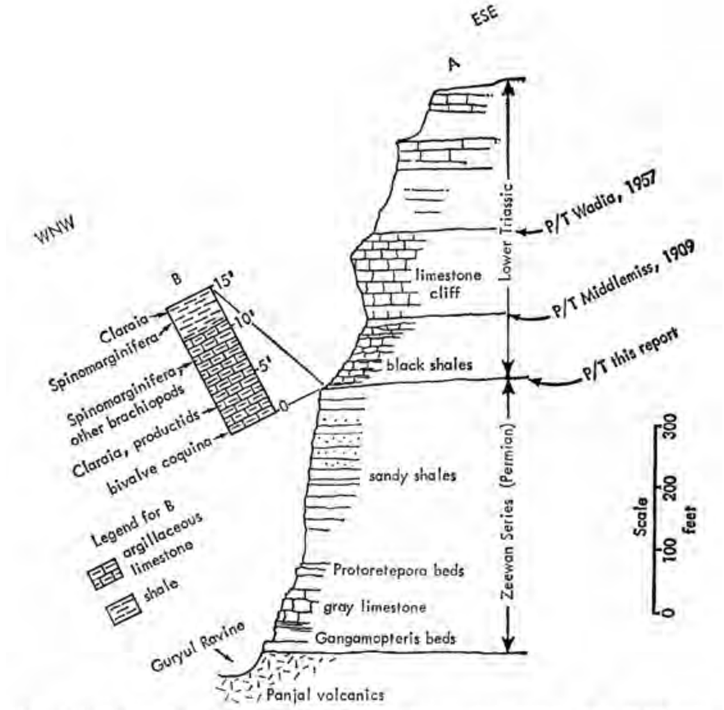


Fig. 1. Southeast side of Guryul Ravine. (A) Stratigraphic section after Middlemiss (1909) [adapted from Wadia (*4*)]; *P/T*, Permian-Triassic boundary. (B) Basal part of Middlemiss's "Black Shale" unit according to our own traverse. (Scale in feet used for compatibility with earlier publications.)

Figure 2: *Teichert & Kummel, (1970), fig. 1 with caption.*

Two years later, the Japanese Group leaded by Keiji Nakazawa with Hari Mohan Kapoor from Indian Survey studied the Guryul Ravine and surrounding sections (1971-1972). The extensive results were published in the Kyoto University Memoirs (Nakazawa et al., 1975), the fauna in Nakazawa and Kapoor, 1981 with the ammonoids systematic description by Bando, and during the '80s, Tetsuo Matsuda (1981, 1982, 1983 and 1984) wrote detailed conodont papers on the Kashmir Permian-Triassic succession.

Brookfield start to study Kashmir sections in 1984 and in December 1987, we had opportunity, with Jean Marcoux, Tim Tozer and Maurizio Gaetani to visit and sample the Guryul Ravine section. In 1988, we presented the first Carbon isotopic curve of this section (Baud and Magaritz, 1988) and in 1996, we published with V. Atudorei and Z. Sharp a detailed Carbone isotopic curve and gave our view on the main Permian-Triassic sedimentary evolution (Baud et al., 1996).

As we wrote in Algeo et al, 2007, the placement of the Permian– Triassic boundary (PTB) has long figured in debates. It was a candidate for the Permian– Triassic Global Stratotype Section and Point (GSSP) as the Meishan D section in Zhejiang Province, China (Kapoor, 1996; Yin et al., 1996) but contested by Wang (1990).

The Lopingian (Upper Permian) Zewan Formation overlain by the Lower Triassic Khunamuh Formation in a N 100-m-thick, is showing a conformable marine succession. The basal few meters of the Khunamuh Formation (Unit E1) contain faunal elements that were considered to be indicative of both a Late Permian and an Early Triassic age (Teichert et al., 1970;

Brookfield et al., 2003). According to the formal designation of the base of the *Hindeodus parvus* zone as the erathem boundary (Yin et al., 2001) this " transition interval" belongs entirely within the Upper Permian (Baud, 2001; Shen et al., 2006). The first specimens of *H. parvus* conodont are found 40cm above the base of Unit E2, a level also marked by the appearance of Lower Triassic ammonoids belonging to the genera *Otoceras* , *Lytophiceras* , and *Glyptophiceras* (Bando, 1981).

The conodont biostratigraphy of the section (see Fig. 3) has been worked out in detail (Murata, 1981; Matsuda, 1981, 1982, 1983, 1984). Korte et al. (2010), listed the following conodonts in the E1 Member: *H. typicalis*, *H. praeparvus* and *Clarkina carinata.*

Accordingly, -the Unit D corresponds to the Late Permian *changxingensis* zone;
-the Unit E1 to the latest Permian *latidentatus–meishanensis* zone;
-the Unit E2 to the Early Triassic *parvus* and *isarcica* zones;
-the Unit E3 to the *carinata* , *kummeli* , and lowermost *dieneri* zones.

Recently Brosse et al. (2013), published an abstract on conodonts of the E3 unit and Ph. D. work of M. Brosse is in progress.

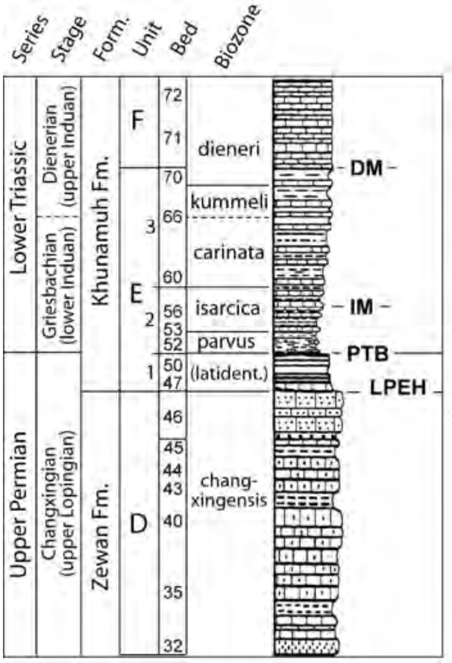


Figure 3: *conodont biochronology of the Permian-Triassic transition (42m thick) at Guryul Ravine (part of figure 8 in Algeo et al., 2007); LPEH: Late Permian event horizon*

2- Permian birth and evolution of the Indian passive margin

At the end of the Palaeozoic the continents were gathered together to form the Pangean supercontinent and in its southern half, India and Australia formed part of the Gondwana continent as well as Africa, and Antarctica (Scotese 2014). During the Late Carboniferous-Earliest Permian period, the Gondwana continent was subjected to glaciation.

The timing of rifting and drifting stages are still under controversy. According to Garzanti et al. (1996, 1998, 1999) rifting processes occured during Carboniferous and drifting stage in the early Permian.

Below we are giving our point of view as discussed by Baud et al. (1989), by Baud in Stampfli et al. (1991, and developed in Baud et al. (1996). Same rifting timing is given in Chauvet et al. (2008). The Northern part of the Great-India has been subject to an early rifting phase in the late Paleozoic, just at the end of the large scale gondwanian glaciation. The beginning of the rifting processes is marked by large hiatus and discontinuities (paraconformities) between the early or middle Permian sedimentary succession and the discontinuous late Permian transgressive sediments. The asymmetric rifting geometry consists of: -a northern lower plate, the present Karakoram continental crust with their former sedimentary cover -a southern upper plate, the present High and Lower Himalayas and small part of the Indian craton and their sedimentary cover (from Zanskar, Chamba, and Kashmir synclinorium to the Salt Range). If the lower plate evolves into an active margin during the Late Mesozoic, the upper plate corresponds to the future Mesozoic-early Cenozoic Indian passive margin. From the Indian craton to the rift proper, the rift geometry can be reconstructed as shown on Fig. 4 below.

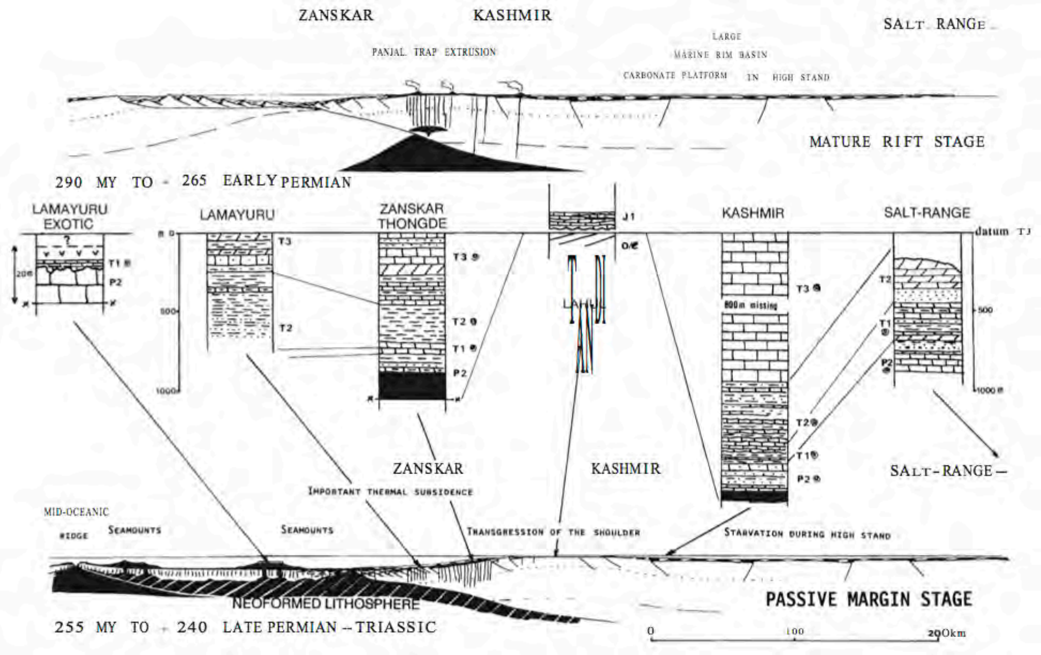


Figure 4: *sketch of the early and of the late Permian Indian rift and Tethyan margin, with some lithological sections (Stampfli et al., 1991, fig. 5 modified)*

The rim basin is found in the Potwar/Salt Range area. The rift shoulder is in the Kashmir Himalaya, and part of it in the underthrusted Lower Himalaya. The compartments of the central part of the rift are represented now by the Zanskar sedimentary belt. Compartments appearing during the earliest drifting stage have been found in the exotics of the Indus or Spongtang colored melange.

From early transtensional extension (Carboniferous) to rifting and drifting (early Late Permian to early Triassic time), the geodynamic and sedimentary evolution of that margin is characterized by the following events:

- a former transtensional extensional event during late Carboniferous in some part of the High Himalaya (Garzanti et al., 1999);
- a voluminous extrusion of "plateau basalts" (over 100 000 km^2), the Panjal Traps (Shellnut et al., 2014), found mainly on the rift shoulder during the early to middle (?) Permian;
- a middle Permian large carbonate platform indicate marine transgression in the rim basin;
- a block tilting and uplift phase with erosion processes occurs on the shoulder during the early Lopingian.
- The marine submersion of the shoulder indicates the beginning of the thermal subsidence and the transition to the drifting stage (late Wujiapingian - Changhsingian). The main consequences are a general starvation and hiatuses as we can observe in the rim basin (laminated dark silty to sandy deposits of the top of the Chhidru Formation) and on the rift

side of the shoulder with phosphatic shales deposits of the upper Kuling Formation (Baud et al., 1984; Gaetani et al., 1990; Garzanti et al., 1994; Nicora et al., 1984). As shown by the study of large exotic blocks (Reuber & Colchen, 1987; Bassoullet et al., 1978) highly microfossiliferous lime packstones (*Colaniella* limestones) grew within trachytic volcano - sedimentary deposits during the youngest Permian (Changhsingian), on uplifted compartments of the intermediate (and oceanic?) crust;

- With the following worldwide sea-level rise and transgression, an important change in sedimentation occurs at the end of the Permian. In the Salt Range, high energy dolomitic grainstones with glauconite (middle Kathwai Member) transgress over dolomites of the lower Kathwai Member or locally, directly on the starved uppermost Chhidru deposits. On the former shoulder (Kashmir), deepening marine conditions are indicated by open marine siliceous shales.

Seaward, very condensed cephalopods limestones occur (basal Lilang Group of Zanskar and Spiti). On the seamount Lamayuru exotic (Bassoullet et al., 1978) a manganese crust deposit is directly lying on the Changhsingian *Colaniella* limestone.

3- The Permian, Permian-Triassic transition and the Triassic deposits on the Indian passive margin, Guryul Ravine section.

At the base of the Guryul Ravine section the very thick Panjal Traps flood basalts is croping out, and its lower part is now dated at 289±3 Ma (Sakmarian, early Permian; Shellnutt et al., 2011, 2014). The overlying Gangamopteris beds, about 15 m. thick consist of siliceous shale and novaculite. Above, **the Zewan Formation** is about 100 m. thick and has been subdivided by Nakazawa et al. (1975) in four members, named A to D (Fig. 5). The same authors divided the Khunamuh Formation into six members, named E to J on the basis of variation in carbonate content.

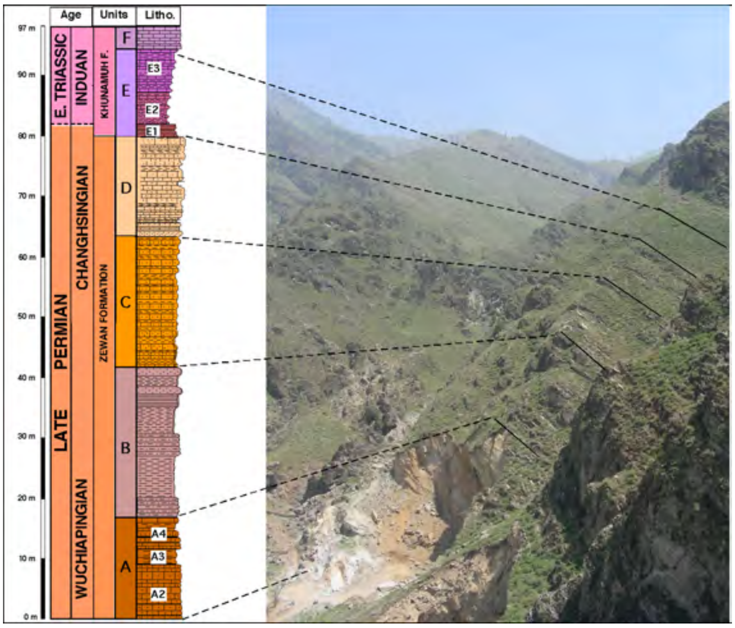


Figure 5: *lower part of the Guryul Ravine section with corresponding field slope view.*

As shown in Figure 5, Member A of the Zewan Formation, 26 m thick, consist of limestone, locally with silty shales (fossil range in Fig. 6) . Member B, about 30 m thick, comprises shale with carbonate lime mudstone. Member C (23 m thick) is represented mainly by calcareous sandstones and by sandy shales. Member D (18 m thick) is characterized mainly by thick-bedded sandy limestone and channelized calcareous sandstone with slump deformations.

Members C and D of the Zewan Formation are characterized by the predominance of gastropods and bivalves.

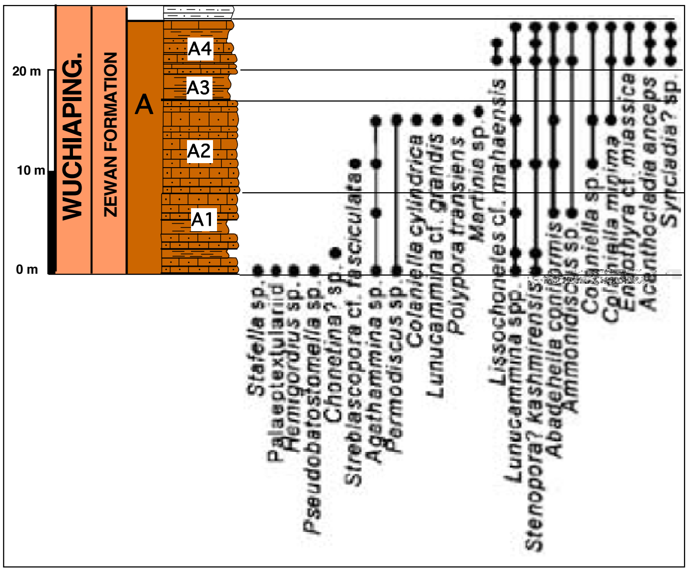


Figure 6: *Fossil range chart of the base of Zewan Formation (Unit A, in Shen et al., 2006).*

As co-author of the Algeo et al. (2007) paper on Permian-Triassic Boundary at Guryul Ravine, we will resume our results on the Permian-Triassic transition in the following lines.

The uppermost 5 m of the Zewan Formation (Unit D, Beds 43– 45) consist of bioturbated, fine- to medium grained, well-sorted, argillaceous sandy limestones or calcareous shaly quartz sandstones, with minor shaly interbeds (Fig. 7, Brookfield et al., 2003). Many of the coarser-grained beds exhibit grading from parallel lamination to hummocky cross-lamination typical of deposits of waning storms.

Slumping in parts of the Member D suggests sediment deposition in a slope setting, with soft sediment deformation possibly triggered by storm waves or earthquakes (Brookfield et al., 2013). The uppermost bed of the Zewan Formation, numbered D 46 by Nakazawa et al., 1975, has been the subject of very detailed description by Brookfield et al., 2003, 2013, and by Algeo et al., 2007. We will look it in detail at our stop 6, p.19.

The overlying **Khunamuh Formation** exhibits a pronounced change in lithology (Nakazawa et al., 1975; Nakazawa and Kapoor, 1981; Brookfield et al., 2003) The basal Unit E about 16 m thick, consists of interbedded dark calcareous shales and argillaceous limestones as Unit F, and is overlain by pure limestone, cliff forming Unit G.

The transition Unit E1 is a 2.5-m-thick unit dominated by silty gray calcareous mudstones with subordinate thin interbeds of fine-grained quartz siltstones and fossiliferous limestone lenses. The biota (Fig. 7) consist of mostly brachiopods (especially *Strophomenida*) and bivalves as small, probably dwarfed forms . The good preservation, and angularity of the shells and shell fragments, the lack of sorting suggest a parautochthonous origin, with genesis of the more carbonate-rich horizons through winnowing (Brookfield et al., 2003).

Up-section within Unit E, sediments become darker, less quartz-rich, and more argillaceous, limestone beds become thinner and less common, and the fauna changes from a relatively shallow-water assemblage composed mainly of brachiopods and rare bivalves to one dominated by thin shelled bivalves and ammonoids. These changes reflect a substantial increase in relative water depth during the latest Permian and earliest Triassic (events 6 and 7 of Baud et al., 1996).

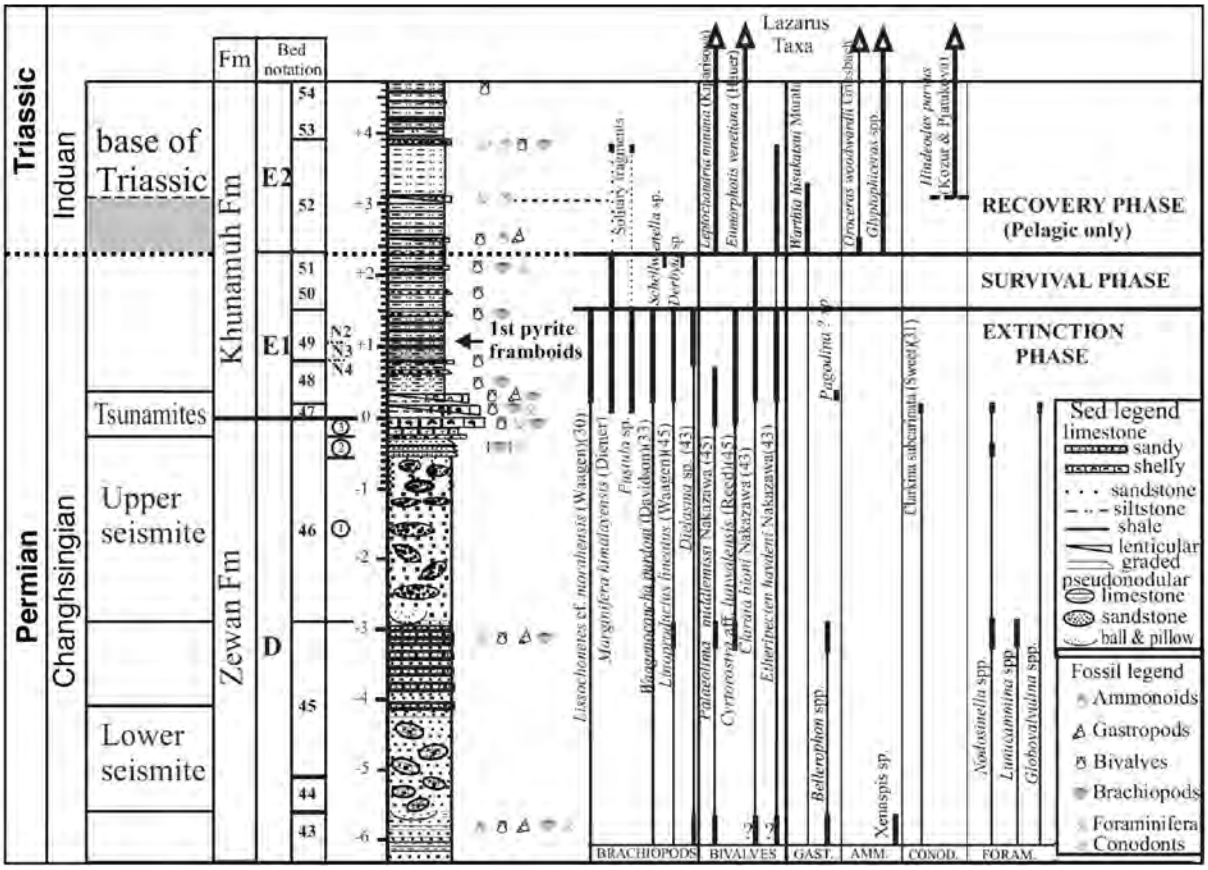


Figure 7: *fossil range from Unit D to Unit E2 from Brookfield et al. (2013, fig. 3 modified).*

According to Brookfield et al. (2013), the end-Permian mass extinction horizon at Guryul Ravine coincides approximately with the top of Bed 49 in the lowermost Khunamuh Formation (Figure 7), within E1 Unit. But fossils are absent in the top of Zewan Formation, a peculiar pseudo-nodular calcareous sandstone, the Brookfield's seismite (Bed 46, Nakazawa et al., 1975) and late Permian brachiopods and bivalves reappear in beds 47–48 of Unit E1 of the basal Khunamuh Formation, in which the fauna is moderately diverse with 14 species. Above, the bed 52 is the only one that contains a mixed fauna of late Permian and Early Triassic taxa.

Tewari et al. (in press) are giving new palynological data on the section.

The water depth of the laminated argillites of the Unit E1 has been tentatively estimated between 50 and 200m by Brookfield et al. (2013) and the sedimentation rates were only moderate (10– 20 m/Myr).

According to Algeo et al. (2007), trace metal proxies provide no evidence for reducing seafloor conditions at any time during deposition of the study section. But according to Wignall et al. (2005), pyrite framboids appear suddenly in the upper part of bed 49, coincident with a shift toward darker sediment. This will be suggestive of development of an expanded oxygen-minimum zone. The controversy is not closed.

The analysis of platinum group elements from the uppermost Permian Units at Guryul Ravine did not give way to a significant extraterrestrial signal (Brookfield et al., 2010).

Unit E2, 6.1 m thick, consists of grey to greenish flaggy shales with intercalated thin continuous limestones yielding ammonoids (including *Otoceras woodwardi*) and *Claraia*. Unit E3, 9.9 m thick is of similar lithology, comprising less fissile black shales intercalated with limestones. The macrofossil taxons recovered from this unit are given at Fig. 8, among them, *Ophiceras sp.* and thin shelled bivalves.

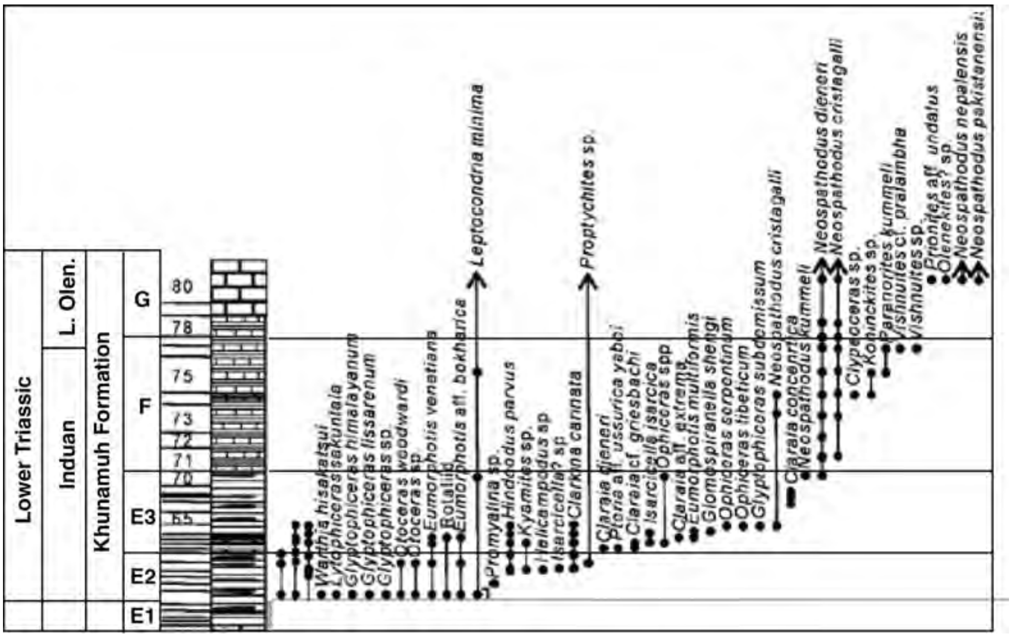


Figure 8: *fossil range chart from Unit E1 to Unit G from Shen et al. (2006).*

Composed of alternating shales and limestones, the Member F is about 20 m. thick and, the cliff forming 30 m thick Member G comprises mostly limestone with rare shale interbeds. Member H, 62 m thick represents shale, thin bedded lime mudstone and nodular limestone. The cliff forming Member I is a 15 m thick limestone unit and Member J consists of alternating lime mudstone with thin shale levels (Fig. 9). Nakazawa et al. (1975) and Kapoor (1996) provided further lithological details on the members of the Zewan and Khunamuh formations. A seismite level occurs at the top of Member H as shown by Leu et al. (2014).

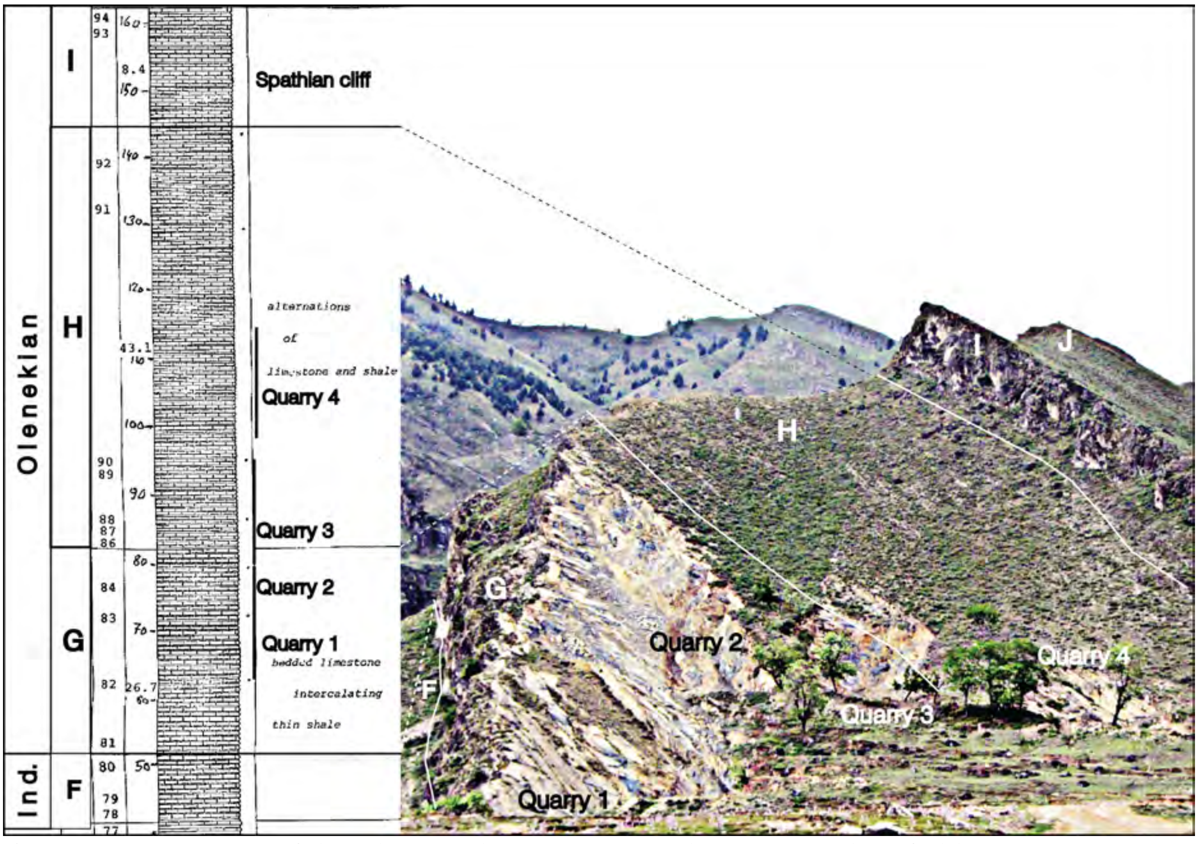


Figure 9: *Upper part of the Khunamuh Formation with corresponding field view.*

4 - Carbon isotope stratigraphy (Fig. 10)

The Permian-Triassic transition and the lower Triassic Carbon isotope stratigraphy of Guryul Ravine are still under study by a team of Zurich University, Switzerland (Marc Leu Ph. D.) and by L. Krystyn with M. Horacek from Vienna University (Austria). These new results are not yet published. We are reporting below the published data from Baud et al. (1996), Atudorei, (1999), and Algeo et al. (2007). Korte et al. (2010), published his own data but with very few changes from previous results. The unpublished master thesis of M. Leu (Ph. D. student for Zurich) is giving a complete lower Triassic C isotope curve from Guryul Ravine, but preliminary results are published in his poster (Leu et al., 2014).

According to Baud, et al. (1989, 1996), the Permian-Triassic boundary is marked by a large δ^{13}C depletion, phenomenon documented worldwide and in part, due to the oxidation and removing of the light organic carbon stored on the emerged continental shelf, following a regression. Positive δ^{13}C values (+2-3‰) occur within Member A (Wuchiapingian). We have no data from B and C members of the Zewan Formation , but within Member D, a large shift of about 3‰ is recorded 5 m below the top of Zewan Formation, during a shallowing phase.

Within the latest Permian transgressive E1 member of the Khunamuh Formation, the δ^{13}C values are more or less constant near 0 (‰ PDB), with a slow trend toward positive values. An anomalous positive value occurs 10cm above the base of E1. We interpret this value as being a result of reworking of upper Permian soft lime sediment (Brookfield et al., 2013 tsunamite 1). Its interesting to note that a same positive pic occurs in the organic carbon curve.

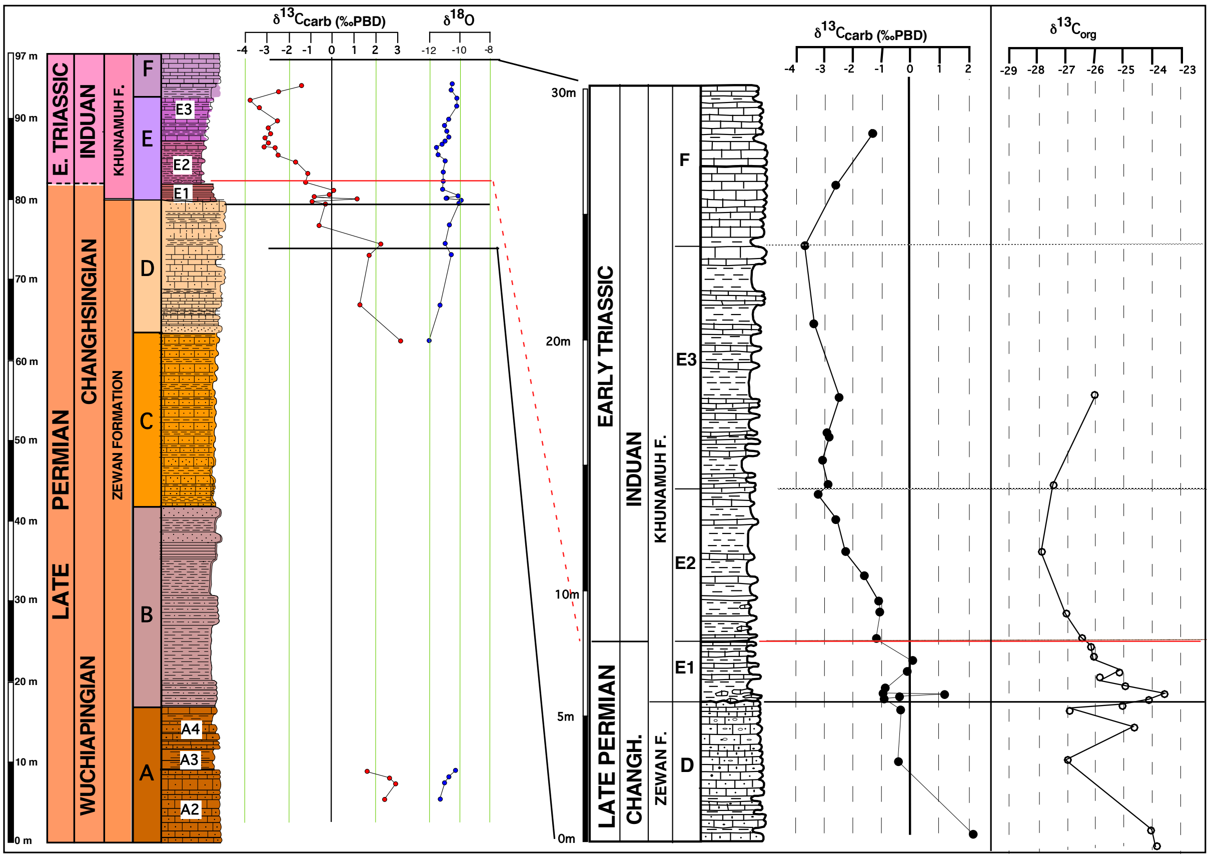


Figure 10: *Guryul Ravine, carbonate* $\boldsymbol{\delta}^{13}$*C data (Baud et al., 1996) and organic carbon* $\boldsymbol{\delta}$*13C data (Algeo et al., 2007) with enlargement of the Permian-Triassic transition (right)*

For Algeo et al. (2007), $\delta^{13}C_{org.}$ ranges from− 23.6‰ to − 27.9‰, and the values are consistent with both marine and terrestrial sources of organic matter. Up-section, these values exhibit a trend toward more $\delta^{13}C_{org.}$ depleted values that is similar to the trend observed in the carbonate $\delta^{13}C_{carb.}$ record (Baud et al., 1996).
Within the early Induan *Otoceras* zone (Member E2 of the Khunamuh Formation), the downward shift in the $\delta^{13}C_{carb.}$ values is gradual and low values (-4‰) are reached in the overlying *Ophiceras* zone (Member E3). This minima trend in the $\delta^{13}C_{carb.}$ curve can be correlated with the similar one observed in the Mazzin Member of Werfen Formation, Southern Alps (Horacek et al., 2007). The same minima is observed within the *Ophiceras* beds at Palgham section (about 80km E of Guryul Ravine, Baud et al., 1996). After the low $\delta^{13}C_{carb.}$ values in Ophiceras zone we note a progressive rise at the base of the overlying Vishnuites zone (late Induan).

It is interesting to note that the $\delta^{18}O$ values are very low, ranging from -9‰ to -12‰ (v. PDB) and show no variations in the carbonate across the boundary.

Notes…..

Part B- Description of the visited outcrops

For November 18 and 19, our itinerary will be the same and is shown below (Fig. 11) on a Google Earth map: the distance from the hotel to the outcrop is about 27 km and due to local traffic the duration is about 40 minutes.

Figure 11: *itinerary from the hotel along the Dal Lake to the Guryul Ravine section*

November 18, 2014 - The Permian and Permian-Triassic transition at Guryul Ravine

The 6 stops of the day are shown on the Google view below (Fig. 12)

Figure 12: *Google view on the Guryul Ravine slope with the main units and the 6 day-stops*

Stop 1: Our first stop will be the late Permian transgression of the Zewan Formation above the lower Permian Panjal Trap and middle Permian Gangamopteris beds (Figs. 13 and 14).

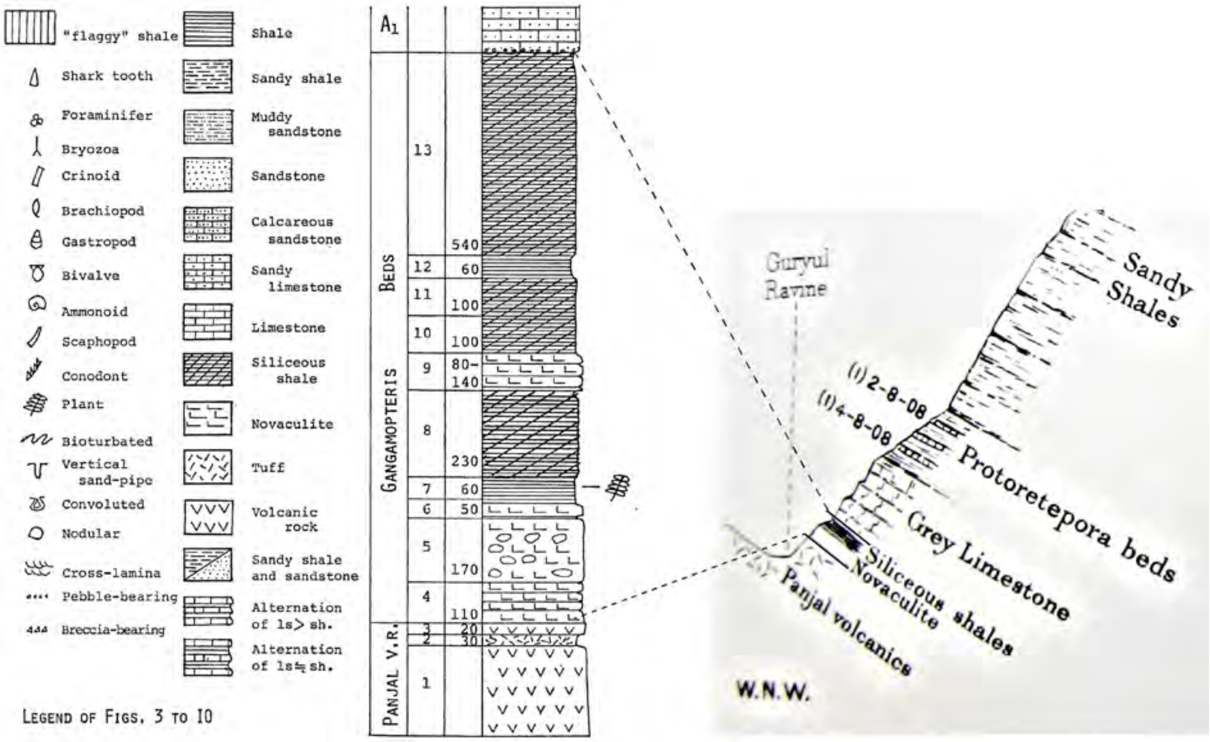


Figure 13: *left, caption and Nakazawa et al.* (fig. 3, 1975) *lithological succession of the Gangamopteris beds ; right, the lower part of the Middlemiss (1910), Guryul Ravine section.*

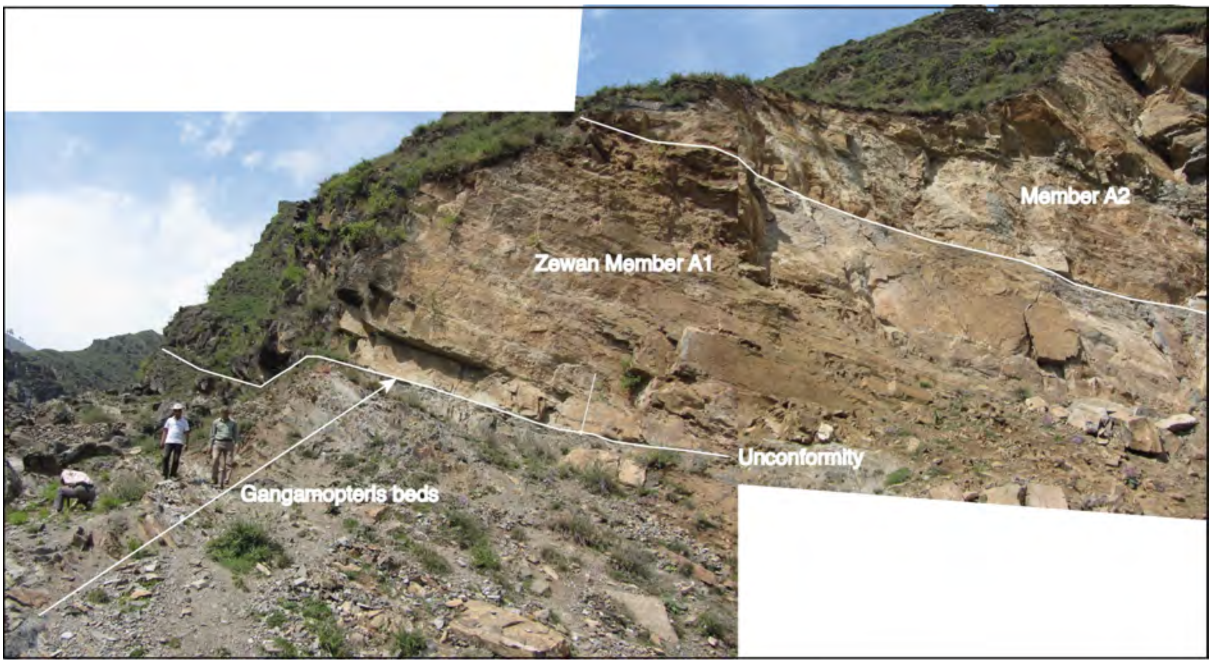


Figure 14: *unconformity of the late Permian transgression (Zewan Member A1) above middle Permian Gangamopteris beds.*

Stop 2: we will look at the Member A (A2 to A4) in the lower Quarry (Fig. 15)

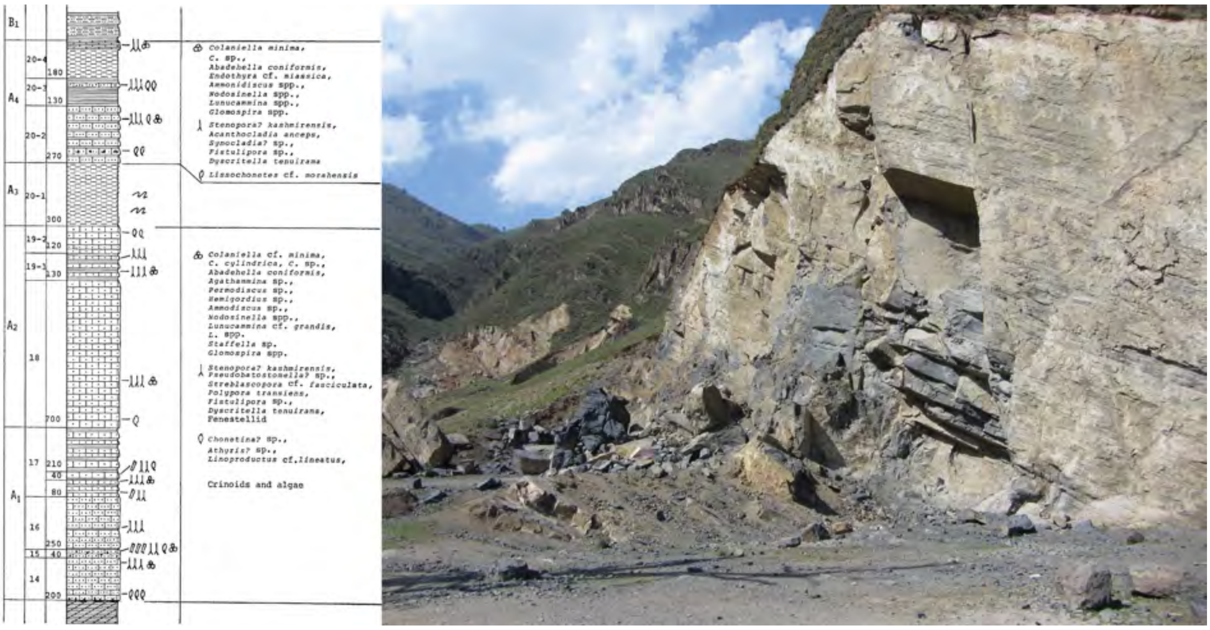


Figure 15: *left, lithological succession of the Member A of the Zewan Formation* (Nakazawa et al., fig. 4, 1975)*; right, view of the limestone wall of the A2 unit.*

A fossil range chart of the Member A is shown in Figure 6 and it is interesting to note that the appearance of the foraminifera *Collaniella* in units A2 and A4 is time related to its appearance in the Kalabagh Member of the upper Wargal Formation in the Salt Range. This Member is dated of the late Wuchiapingian conodont zone (Mei (2002).

Stops 3 to 5, (Figs. 16 and 17): climbing-up on the Zewan slope, we will successively cross and look at the members B, C and D of the Zewan Formation.

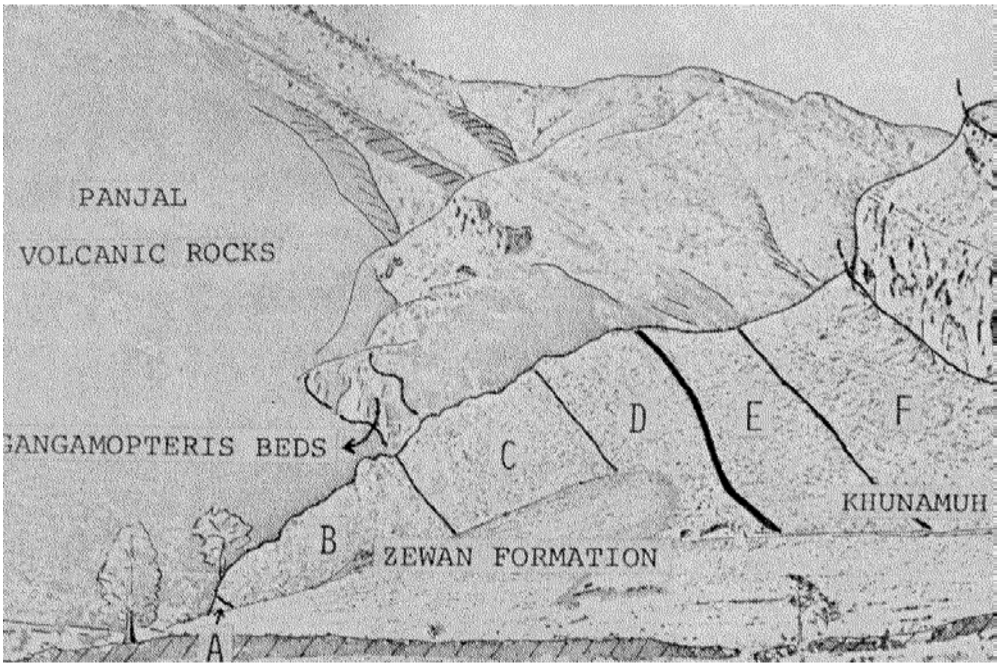


Figure 16: *Nakazawa et al.* (part of plate 1, 1975) *succession of the members B to D of the Zewan Formation and members E, F and G of the Khunamuh Formation.*

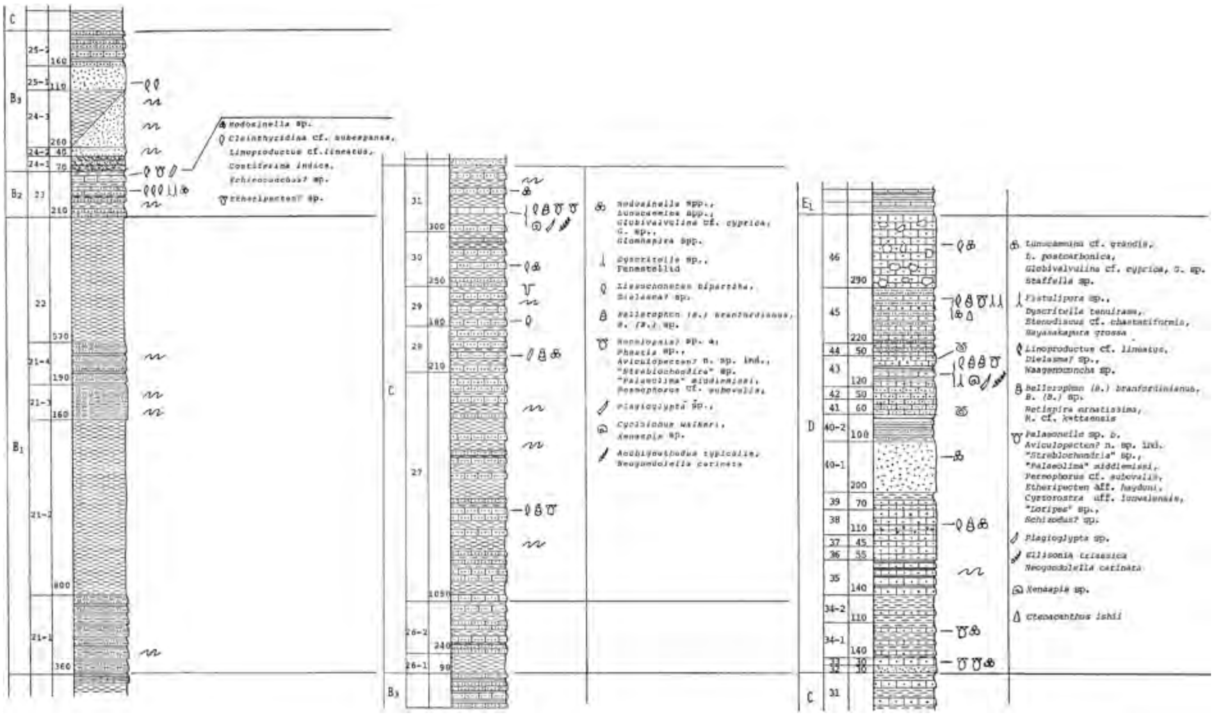


Figure 17: *Nakazawa et al.* (Figs. 6, 7, 8, 1975) *with lithological succession of the Member B (left), C (middle) and D (right) of the Zewan Formation*

Stop 6 (Figs. 18, 19 and 20): the top of the Zewan Formation has been the subject of great attention and detailed sedimentological and geochemical studies (see introduction).

Figure 18: *field view of the top of Zewan Formation and Units E1 to E3 of the base of the Khunamuh Formation.*

Figure 19: *field view of the top of Zewan Formation from the other side of the crest with bed numbering and Units defined by Nakazawa et al*. (1975).

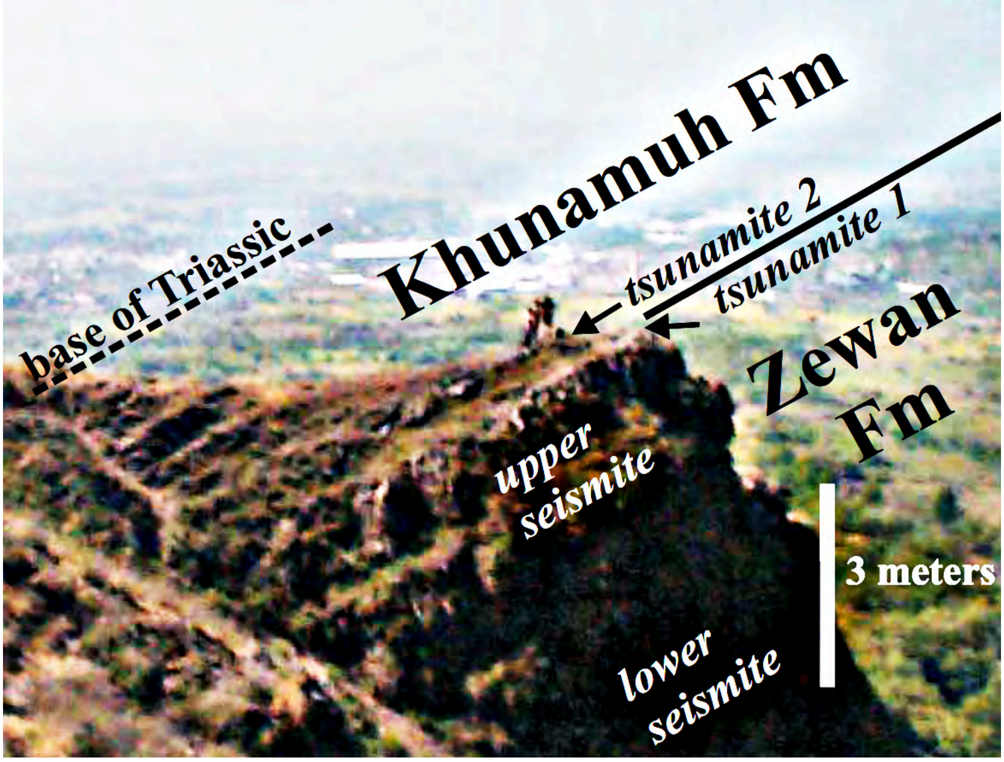


Figure 20: same field view as Fig. 19 but with the interpretation of Brookfield et al. (2013).

The Brookfield et al. (2013) tsunamites hypothesis has been rejected by Krystyn et al. (2014) and seismites revisited by Leu et al. (2014).

Stop 7 (Figs 21, 22 and 23): according to the time left, we will have look at the Induan part of the Lower Triassic, recorded in the Member E and F of the Khunamuh Formation.

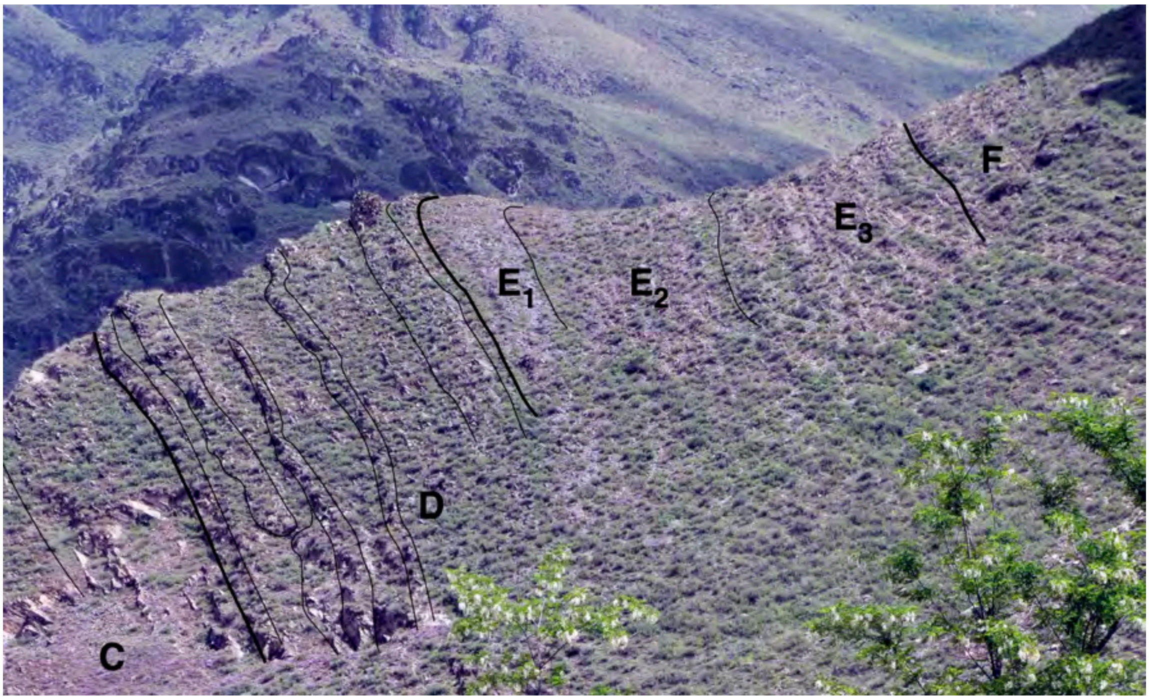


Figure 21: *field view of the top of the Zewan Formation (members C and D) with mass flows, slumped channels and seismite beds overlain by members E and F of the Khunamuh Formation.*

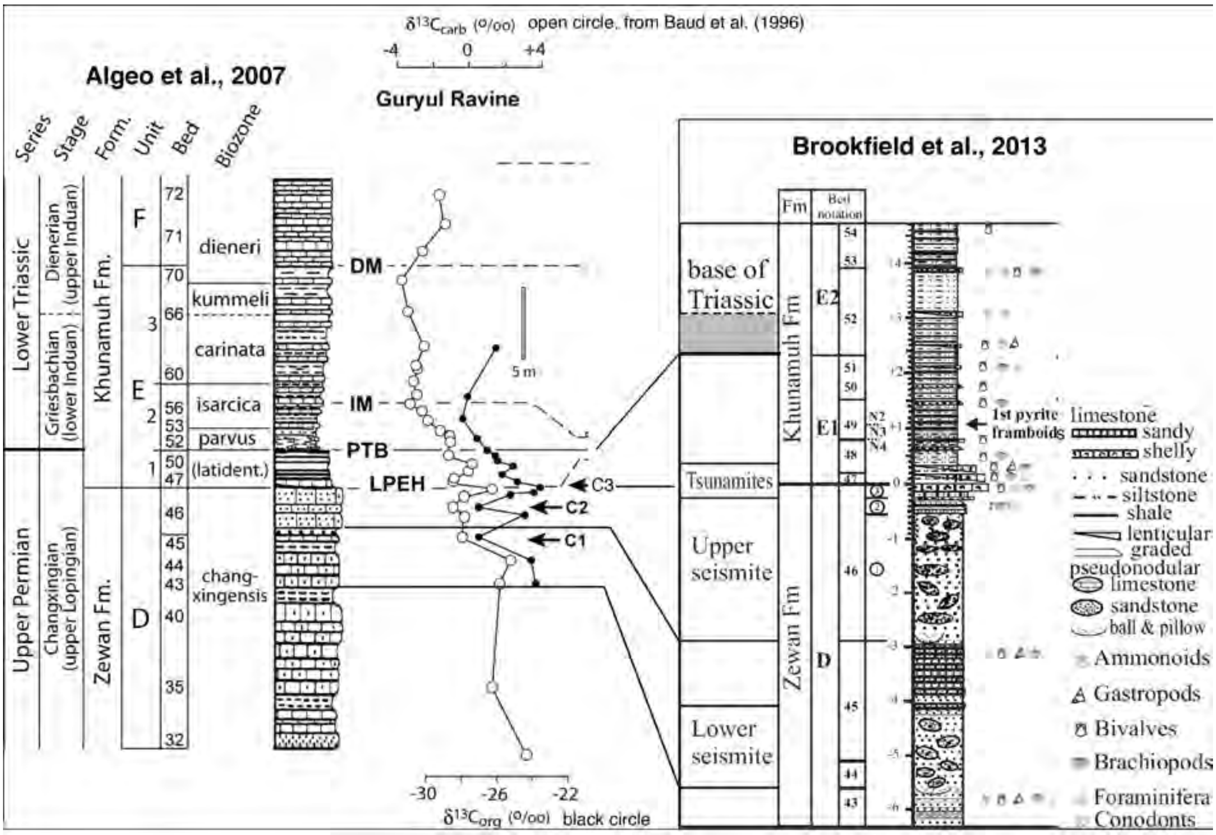


Figure 22: *right, the Permian-Triassic transition with data of Algeo et al.* (2007); *left, detailed interpretation of Brookfield et al.* (2013) *–see also Figs. 3 and 7 and related discussion.*

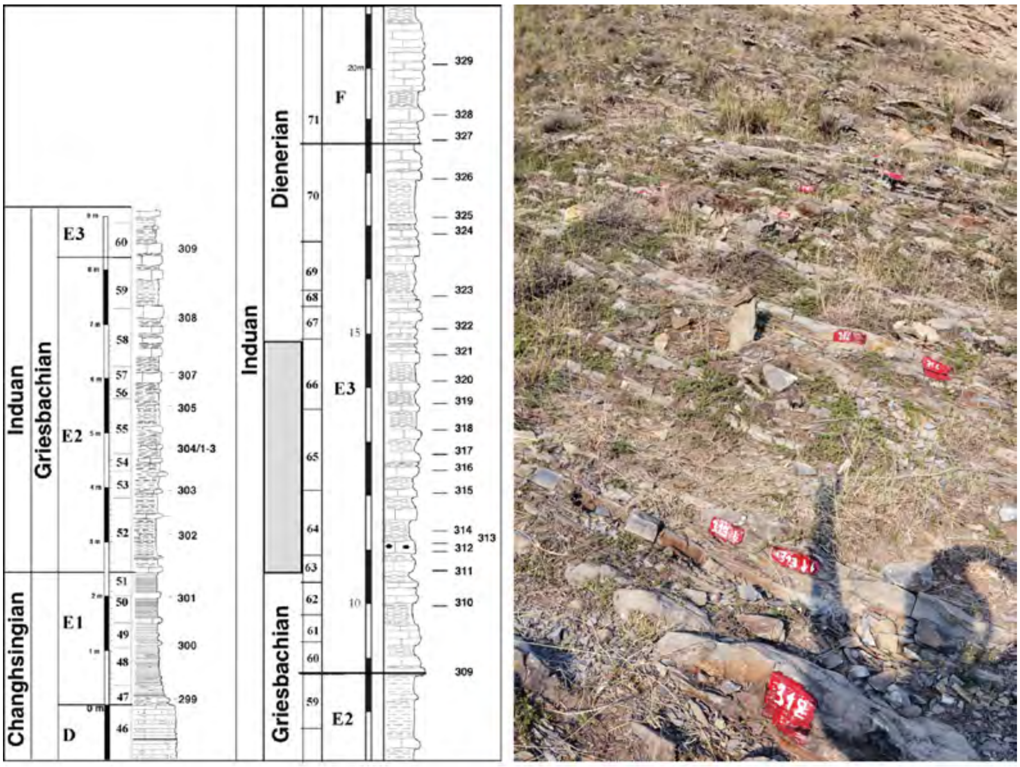


Figure 23: *members E1 to F lithological succession with Nakazawa's numbering and the position of the new sample numbers paint on the beds by Prof. G. Bhat and Ph. D. students from Zurich.*

November 19, 2014 - The Lower Triassic at Guryul Ravine.

Starting from the Hotel Heemal we will move to Guryul Ravine to continue our section from the day before and look at the cliff and quarries open in the Olenekian limestones. The 6 main stops of the day are shown below on the Google view (Fig. 24)

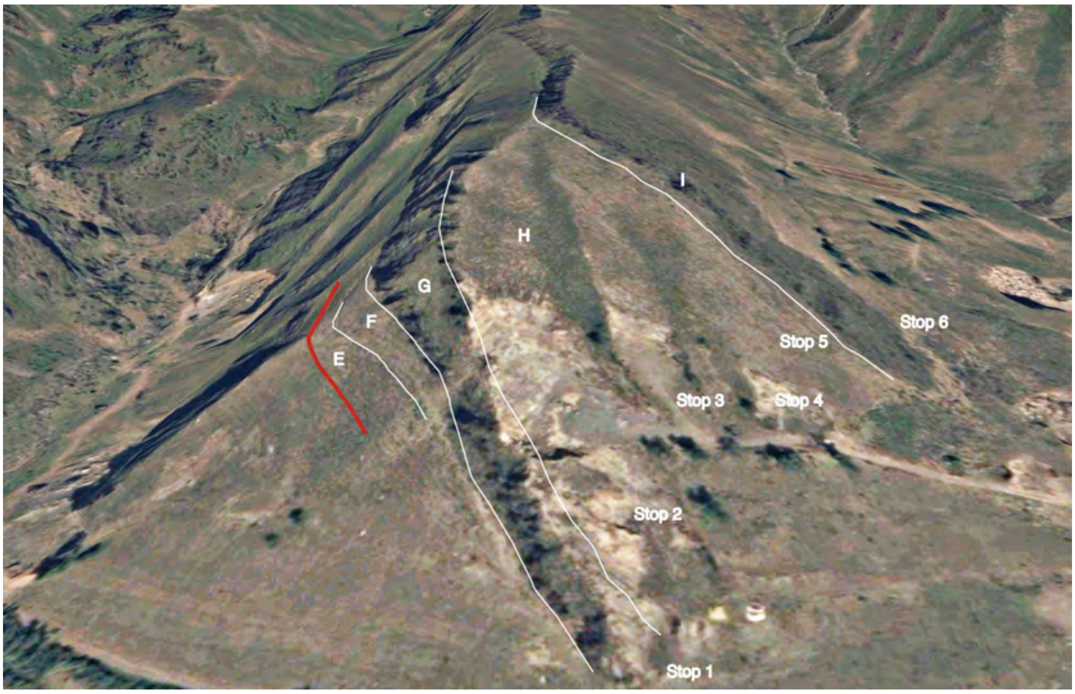


Figure 24: *Google view on the Guryul Ravine slope with the main units and the 6 day-stops.*

Stop1: we will look at the thin bedded limestone along the end base of the lower Olenekian cliff (Fig. 25)

Figure 25: *lower part of the Unit G limestone cliff (Smithian).*

Stops 2, 3 and 4: during our next stops 2, 3 and 4 we will examine the middle Olenekian limestone in the 4 recent quarries as shown in the next figures (Figs. 26 to 30).

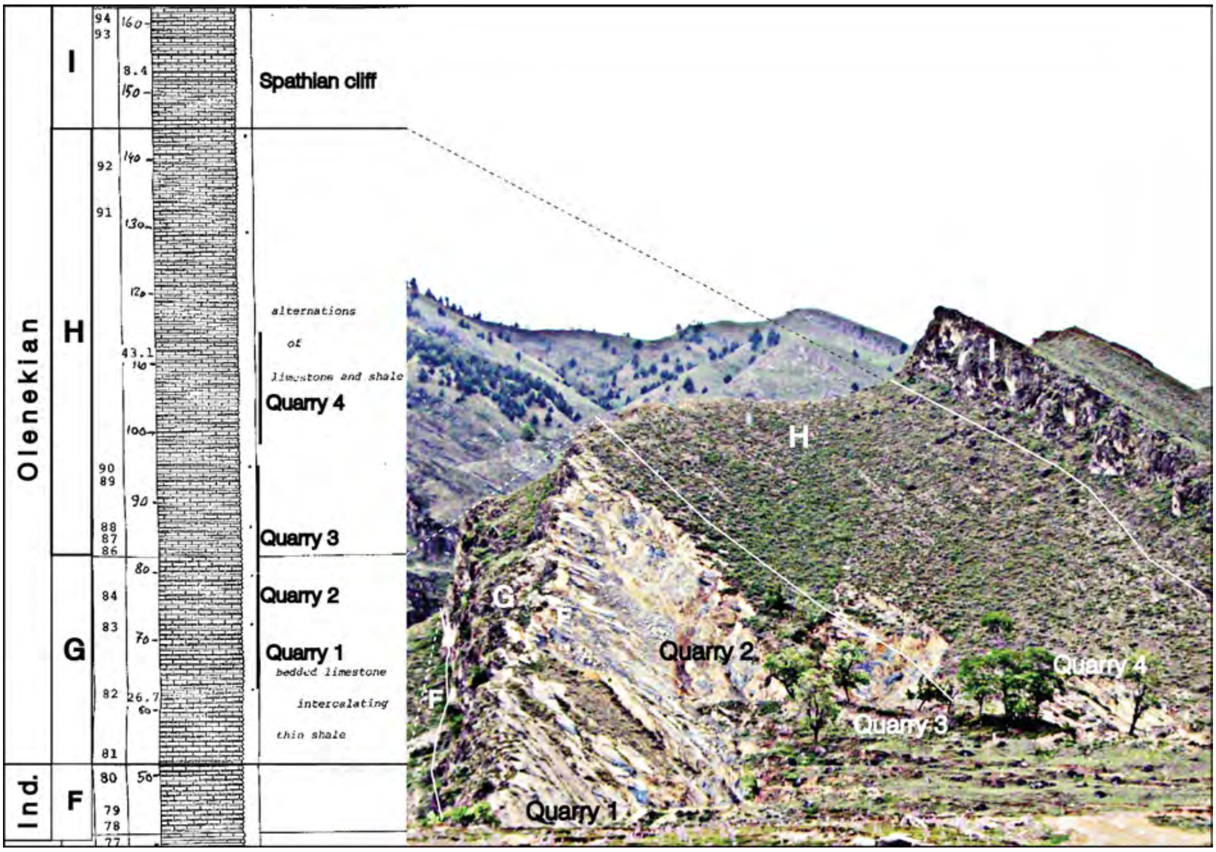


Figure 26: *left, Nakazawa et al.*, (fig. 12, 1975) *with lithological succession of the members G, H and I of the Khunamuh Formation and right, field view of the corresponding units and quarries.*

Figure 27: *wall of the quarry 1, with thick bedded lime mudstone of middle Member G of the Khunamuh Formation (lower Olenekian).*

Figure 28: *wall of the quarry 3, with thick bedded lime mudstone in the lower part (upper Member G) and very thin bedded limestone in the upper part (lower Member H, Olenekian).*

Figure 29*: hardground filled with middle Smithian ammonoids in a block of the quarry 3.*

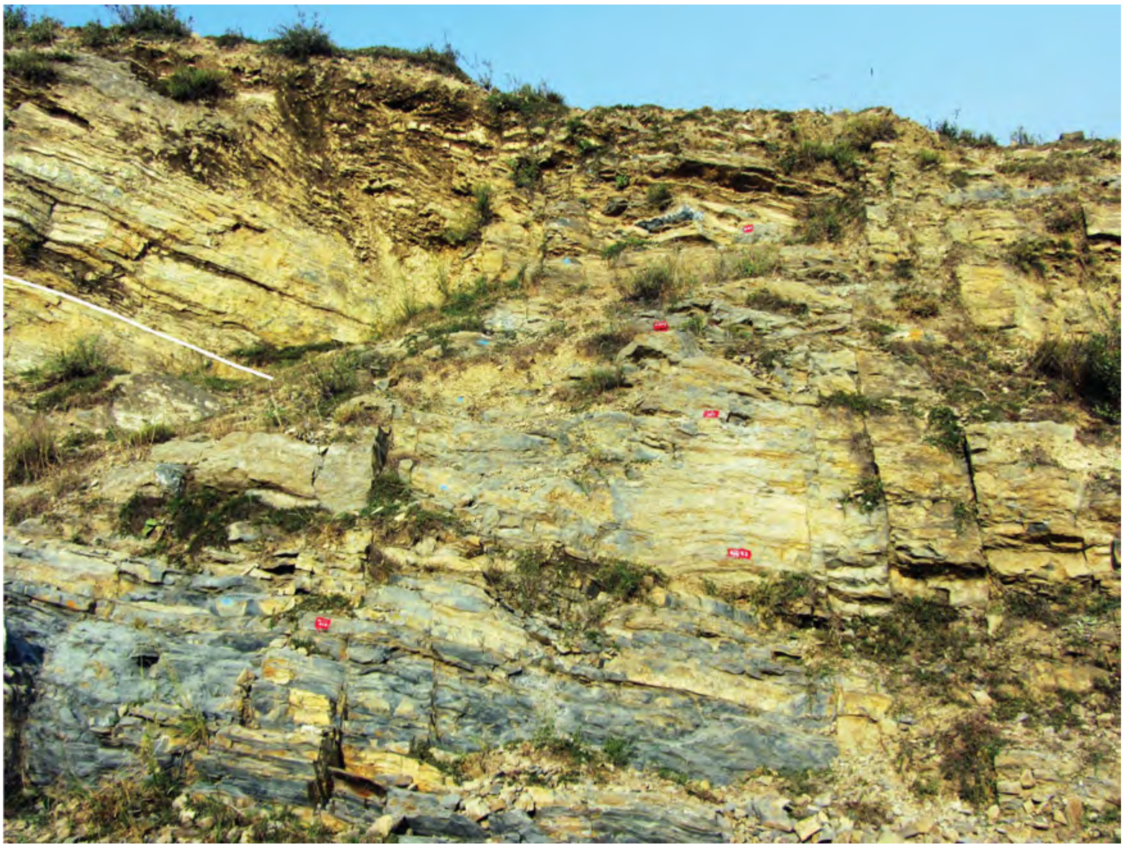


Figure 30: *wall of the quarry 4, showing the very thin bedded limestone above the white line with some shale in the upper part (middle Member H, lower Olenekian). Numbered red marks remind Marc Leu sampling and blue spot Leo Krystyn sampling*

Stop 5: examination of a new lithological unit within the upper part of Member H: the light nodular limestone, upper Olenekian in age (Fig. 31) with a seismite level at the top (Leu et al., 2014).

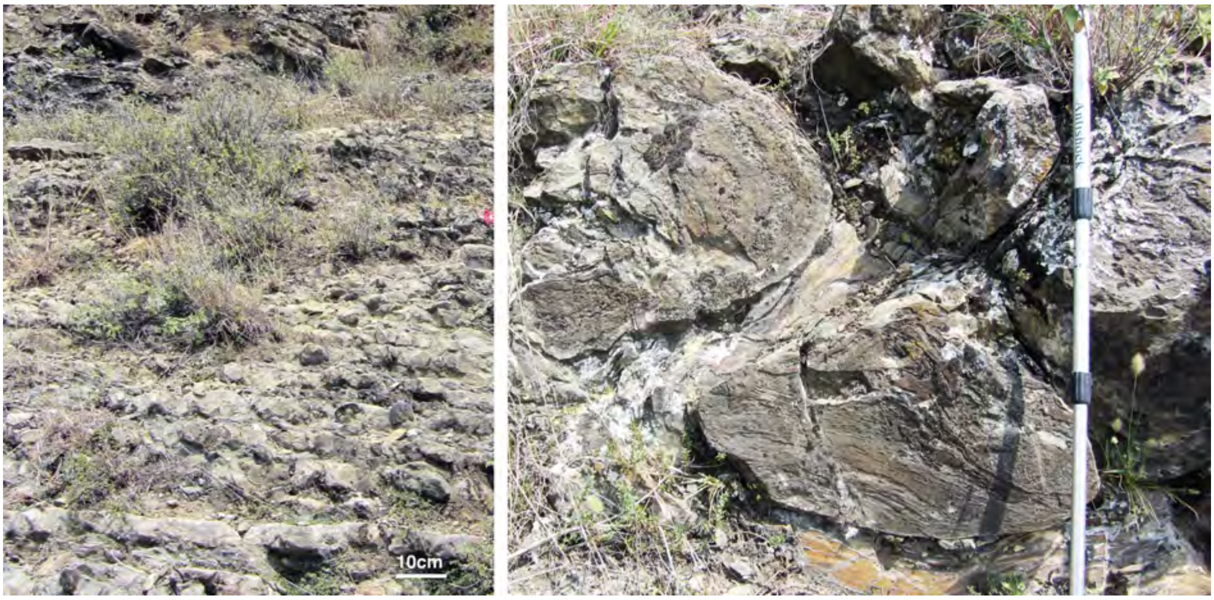


Figure 31: *left, the light, nodular limestone with regular 10cm thick bedding; right, seismite deformations at the top of Member H of the Khunamuh Formation (upper Olenekian).*

Stop 6

Above the nodular limestone we will look at the cliff forming Member I. Due to the stop of terrigenous input, the thin bedded lime mud (distal turbidites) became amalgamated and forms wall without marked bedding plane (Fig. 32).

Figure 32: *typical wall of the upper part of the Member I of the Khunamuh Formation (upper Olenekian) with massive limestone build up by amalgamated distal turbidites.*

For November 20 and 21, 2014 our itinerary will be in part the same area, about 20 km East of Guryul Ravine and is shown below on a Google Earth map (Fig. 33):

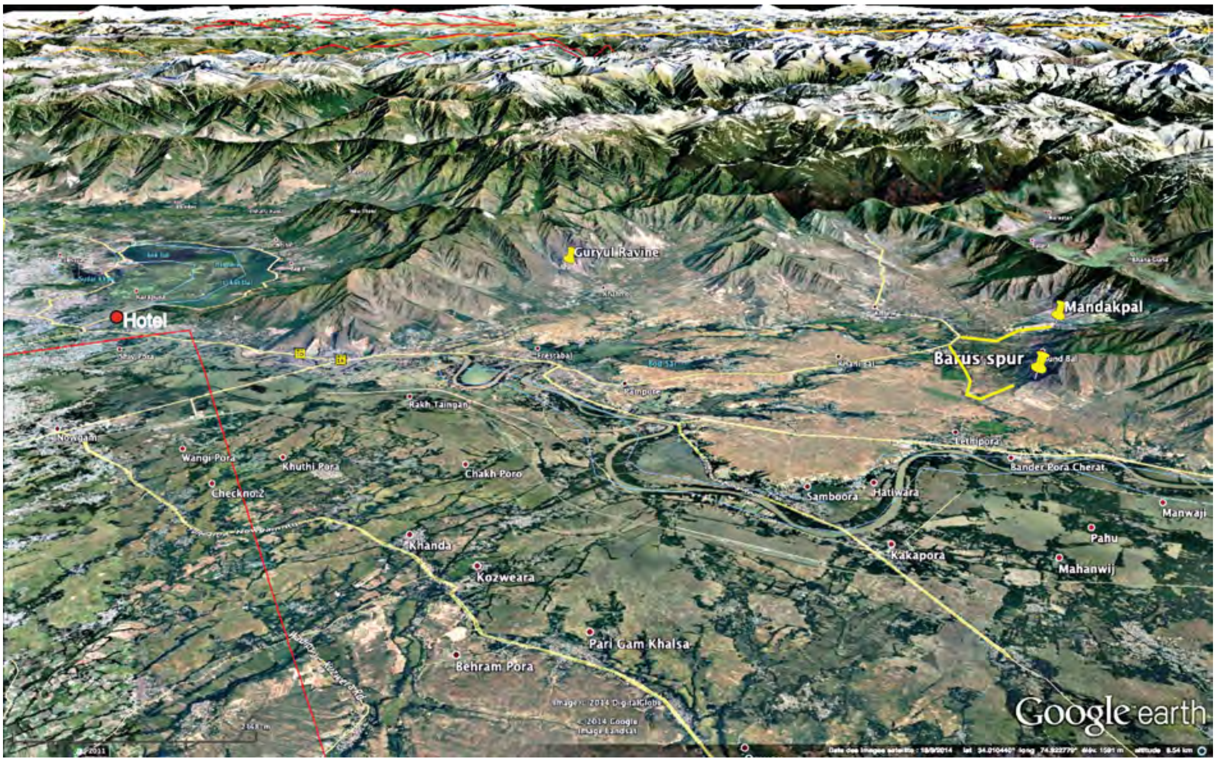


Figure 33: *itinerary from the hotel along the Dal Lake to the Mandakpal and to Barus spur sections*

November 20, 2014 - The Permian and lower Triassic in the Mandakpal area (Fig. 34)

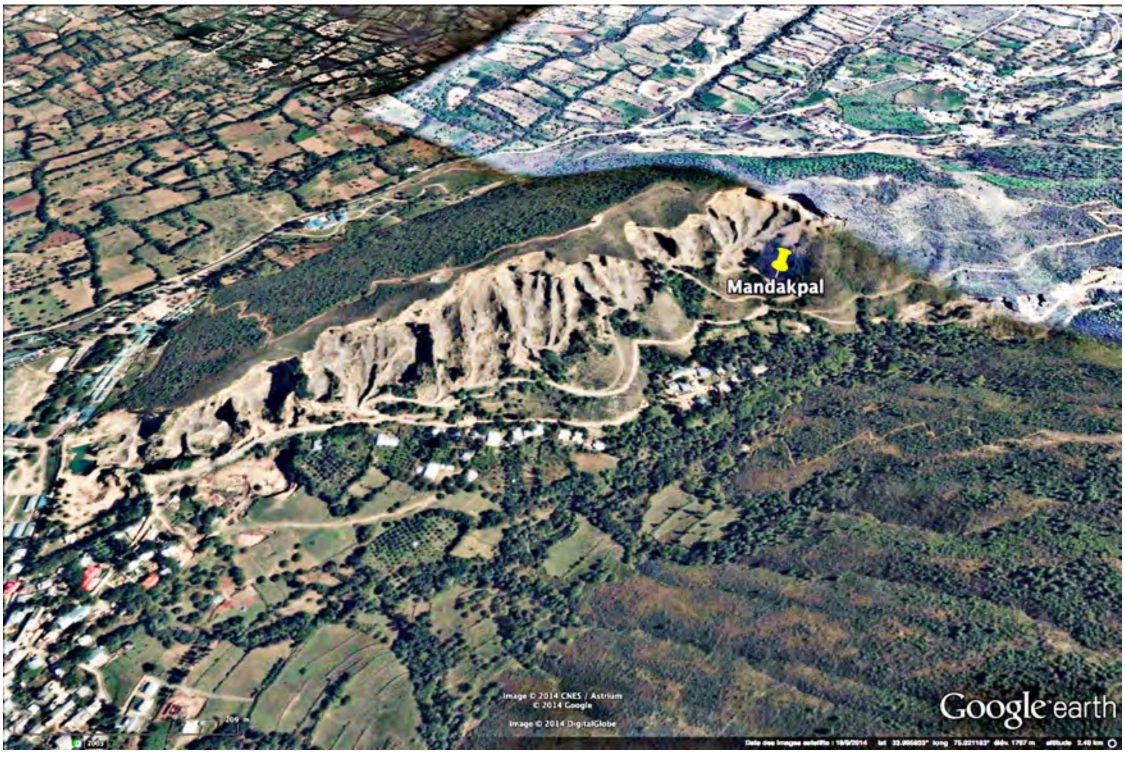
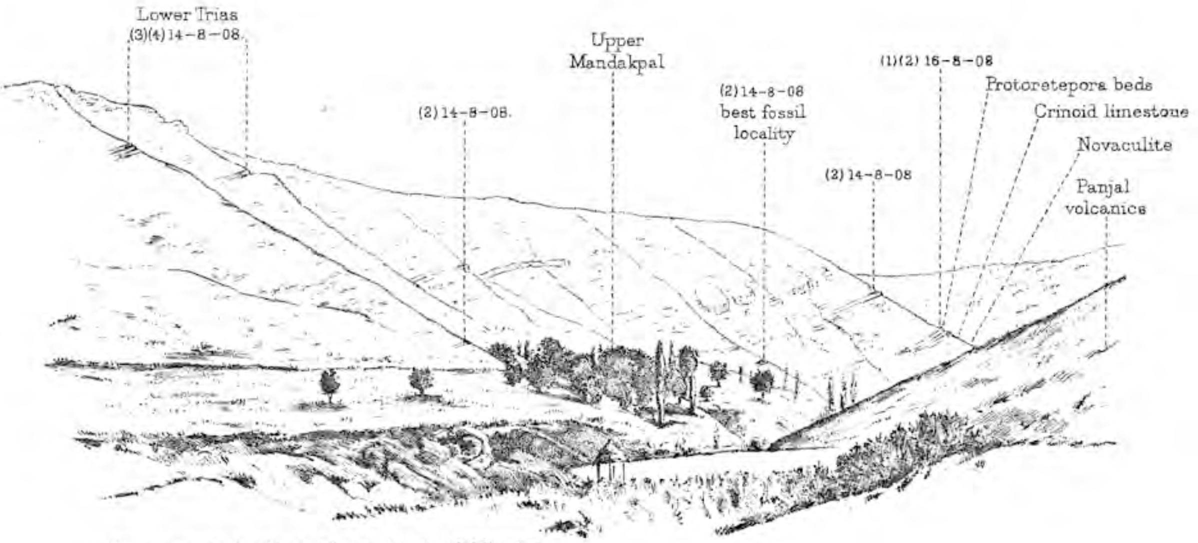


Figure 34: *Google Earth view on the Nandakpal quarries build in the lower Olenekian limestone*

More than a Century ago, Middlemiss (1910) made a survey of the Mandakpal valley and published the drawing shown below (Fig. 35) and a lithological section.



From camera lucida sketch by C. S. Middlemiss.

Figure 35: *the Middlemiss* (1910) *drawing of the Mandakpal Valley with the main stratigraphic levels.*

During our field workshop in this area (6 stops, Figs. 36 and 37) we will look first on the fossiliferous late Permian (Fig.38, best fossil locality of Middlemiss) and on the Permian-Triassic transition (Fig.39)

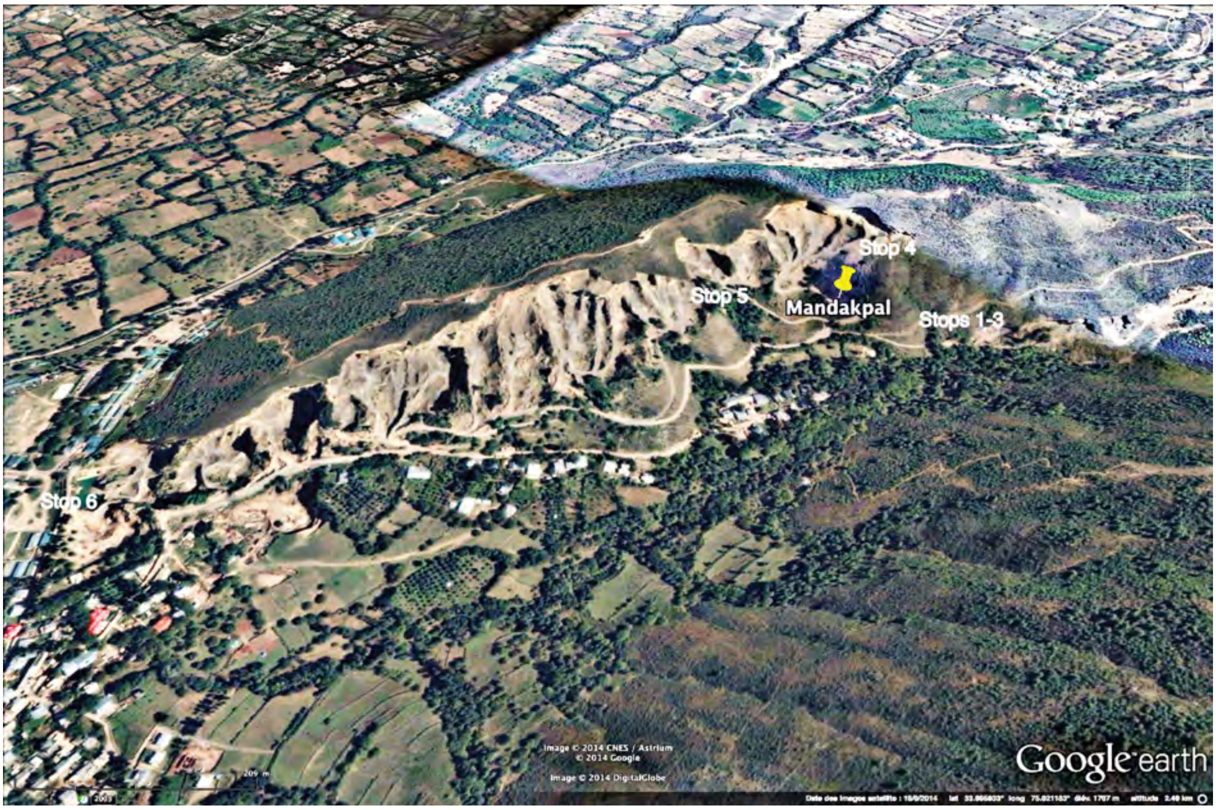


Figure 36: *Google view on the Mandakpal Valley with the 6 stops of the day.*

Figure 37: *Google view on the Mandakpal Valley upper right slope with the 5 first stops of the day. Red line –faults; yellow line (below stop 3) –PT boundary.*

Stop 1. We will have a quick look at the limestone quarry at the base of the Zewan Formation.

Stop 2. The best fossil locality of Middlemiss consists of very rich brachiopods level of the upper Zewan Formation as illustrated in the photo below (Fig. 38).

Figure 38: *surface view of the Brachiopods rich bed of the upper Zewan Formation.*

Stop 3. The Permian-Triassic transition crops out on the slope as shown in the picture below. Until now there are no detail works done on this section and the correlative Guryul Ravine top Zewan seismite (?) (Figs. 39 and 40) is here overlain by more than 10m of uppermost Zewan lithology (Zewan D up), missing in Guryul Ravine.

Figure 39: *a 15m thick succession from upper Zewan Formation to basal Khunamuh Formation. The seismite (?) level is correlated with bed 46 (top of Zewan Formation) in Guryul Ravine section and unit Zewan D up is missing in Guryul Ravine*

Figure 40: *close view to the correlative Guryul Ravine top Zewan seismite bed (level 1, -2m thick); level 2 is correlative with the lower tsunamite bed of Brookfield et al*. (2013).

Stop 4. We will look at the upper quarry built in the lower Olenekian limestone.
The black limestone shown below (Fig.41) is not yet dated and are still in work (Ph. D. of Marc Leu, Zurich, Switzerland).

Figure 41: *dark lime mudstone at the base of the upper quarry correlated with Member F of the Khunamuh Formation.*

Stop 5. As shown in the picture below (Fig.42), we have a good point of view on the middle Olenekian limestone wall showing 7 distinct lithological units corresponding in part to Olenekian Members F (1), G (2-4) and H (5-7) of the Khunamuh Formation but not yet precisely correlated.

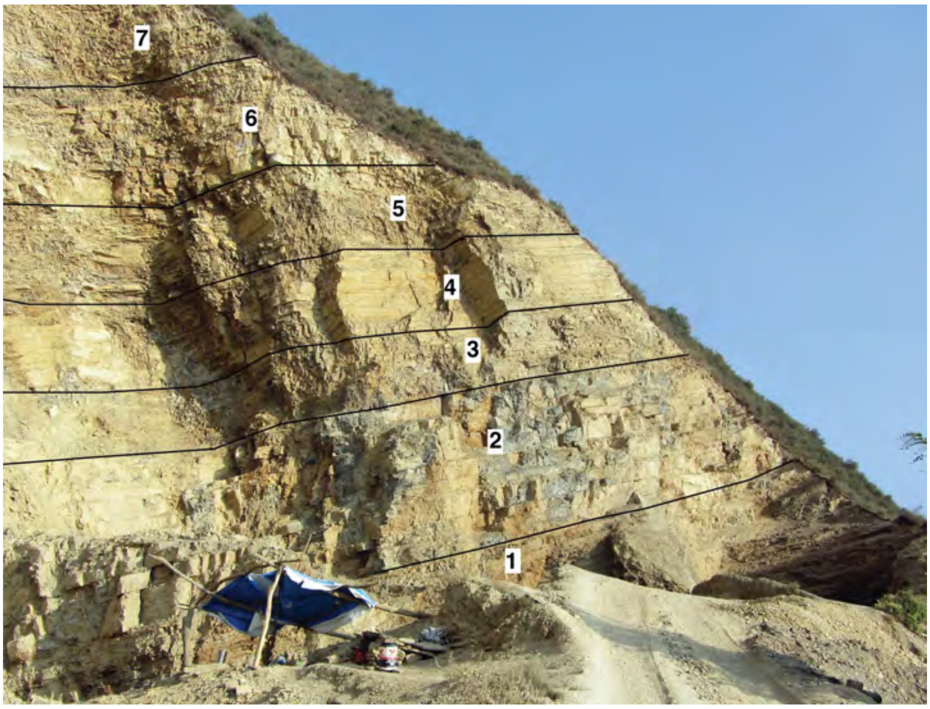


Figure 42: *the upper quarry wall is showing 7 distinct lithological units (see text above).*

Stop 6. Part of the lower Olenekian limestone crop out in the lower Quarry (Fig. 43), but still not yet precisely correlated with members G and H of the Khunamuh Formation.

Figure 43: *view of the lower quarry with the thick bedded limestone of the members G and H of the Khunamuh Formation (lower Olenekian).*

Notes

November 21, 2014 - The Permian and lowerTriassic in the Barus Spur area

The 6 stops of the day are shown on the Google view below (Figs. 44 and 45).

Figure 44: *a Google Earth view of the Barus Spur section with the 6 stops of the day.*

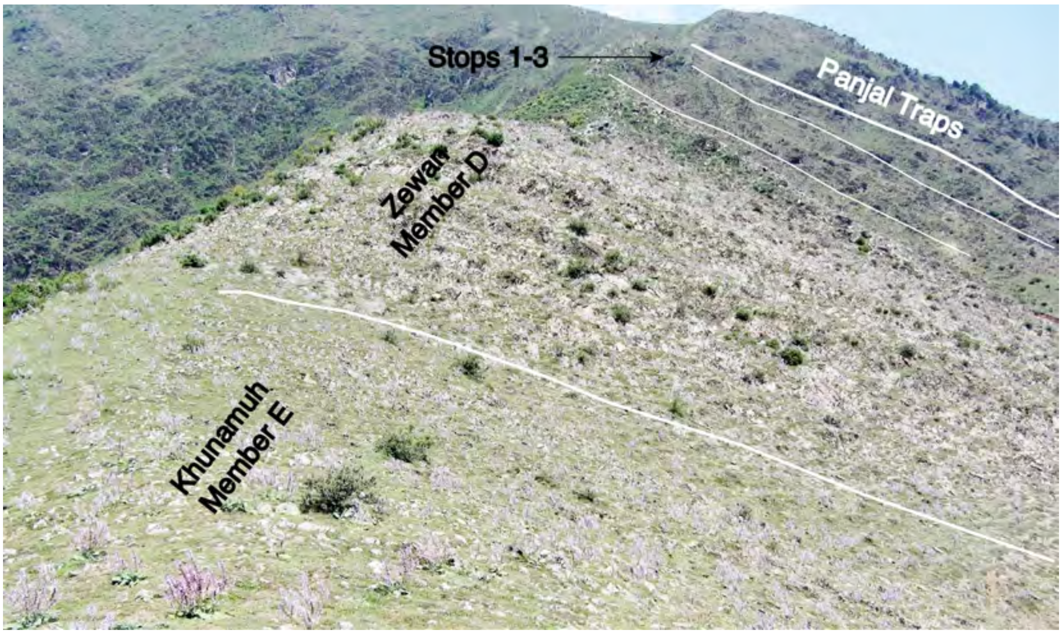


Figure 45: *the Barus Spur section with the Permian-Triassic transition in front (stops 4-5) and stops 1-3 in the ground, above the Panjal Traps.*

Stops 1 to 3. We will have a look to the lower part of the Zewan Formation and the contact with the Panjal Traps (Fig. 46).

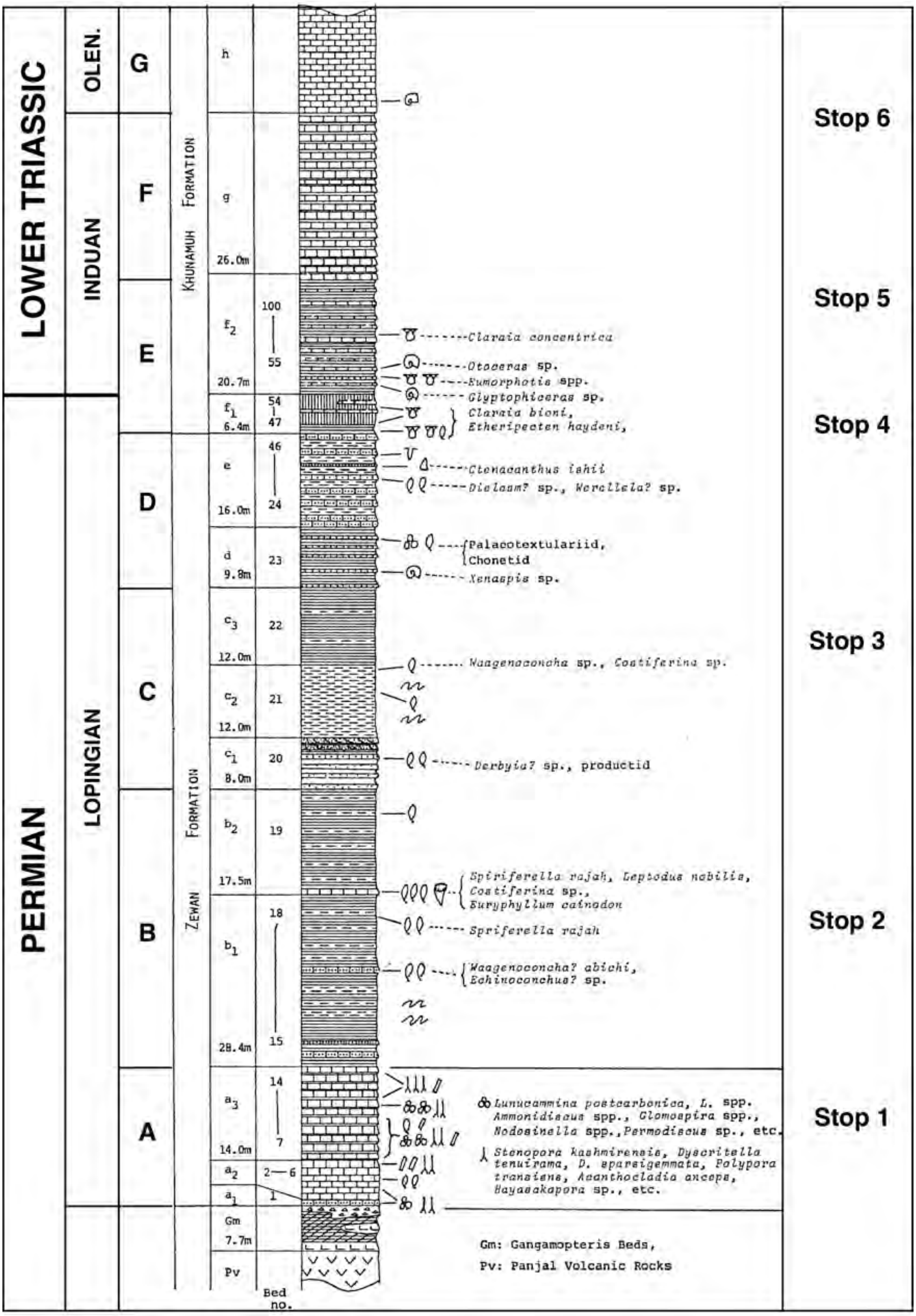


Figure 46: *Nakazawa et al.* (Fig, 11, 1975) *with lithological succession of the Barus Spur section; the units A to F refer to the Guryul Ravine members.*

Stops 4-5. (Fig. 47) We will examine the Permian-Triassic transition (Fig. 47) and make comparaison with the Guryul Ravine and Mandakpal sections. Detailed work on the transition and C isotope studies are still in work by Marc Leu, Ph. D. student from Zurich University. As observed by the Prof. G. Bhat and as in Mandakpal section, the correlative Guryul Ravine top Zewan seismite (?) (Fig. 47) is here overlain by about 7m of uppermost Zewan lithology (Zewan D up), missing in Guryul Ravine.

Figure 47: *view on the top of the Zewan Formation Seismite and Zevan D up) followed by the correlative shally Member E1 of the Khunamuh Formation, about 6 m thick.*

Stop 6. We will look at the shale and limestone succession of the upper part of the Member E and the overlying lime mudstone Member F (Fig. 48).

Figure 48: *view on the Khunamuh Formation, Member E and base of Member F*

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