30. Glacial geomorphology: the paleozoic sedimentary successions of Northern Ethiopia

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Introduction

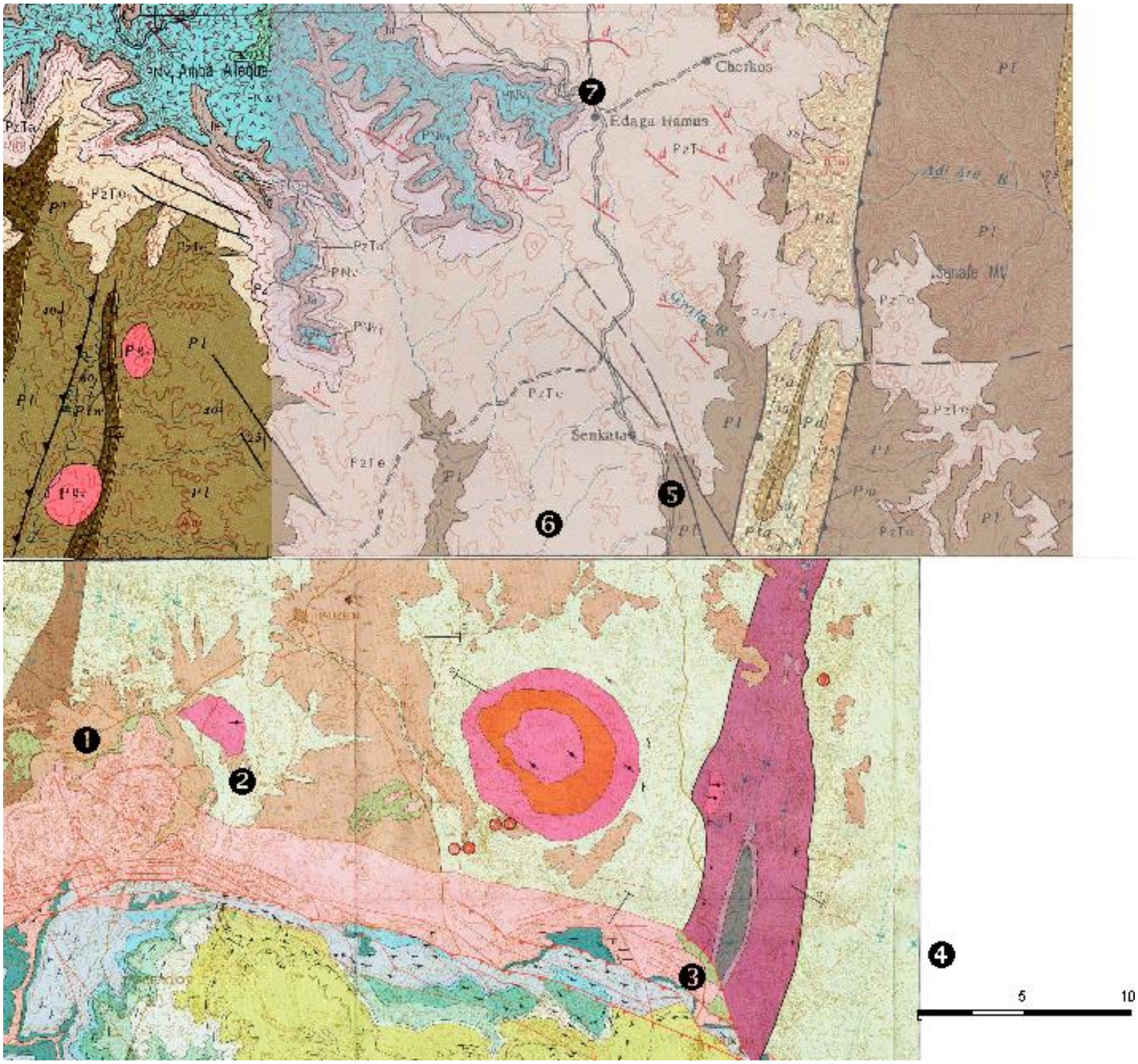
Geology of northern Ethiopia commences with the Neoproterozoic basement rocks at the bottom, unconformably overlain by Phanerozoic sedimentary successions in the middle and thick Tertiary basaltic flows (traps) on the top. Among the Phanerozoic sedimentary successions, Paleozoic is scanty, patchy and thin as compared to Mesozoic, which is regular, much thick and dominant. Traditionally, Paleozoic successions of northern Ethiopia are divided into two lithostratigraphic units; (a) the lower Enticho Sandstone Formation (of fluvial origin) and (b) upper Adaga Arbi Glacial deposits (tillites). Bussert and Schrank (2007) differentiated Lower and Upper Enticho on the basis of their lithic characters and suggested latest Carboniferous to Early Permian age on the basis of palynological evidences. This is further supported by the Sacchi et al. (2007) who have suggested Permian age on the basis of petrographic study of pebbles (of volcanics) in tillite.
The present study is a re-examination of the Paleozoic sedimentary succession of Northern Ethiopia in the light of modern concepts of sedimentary environment, facies and lithostratigraphy. Special emphasis is given on interfingering relationships of the above mentioned two Paleozoic units, to know their paleodepositional environments. Their lithostratigraphic rank (Formation) is also examined. Each lithostratigraphic unit is a product of a unique depositional environment; they are diachronous as they vary in age laterally but always retain their lithological characters (with minimum variations). They may comprise of one, or more than one lithology.

Excursion stops in the study area

Out of the 7 typical locations studied (Fig. 1), 4 will be visited during the excursion:
(3) North of Wukro: outcropping of: LFD, LFE and LFF;
(5) Gumisa, South of Senkata: outcropping of LFC, LFD;
(6) Tsinkaniet: LFA and LFD in the hand-dug well;
(7) Along the road from Senkata to Edaga Hamus: thick cross-bedded LFC.

Results and discussion

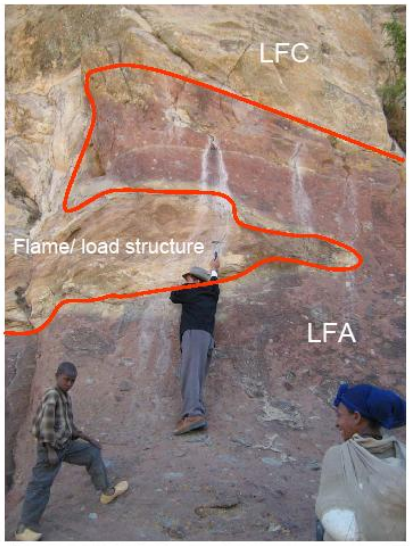
Six major lithofacies were identified in seven sections of the entire Paleozoic succession in the study area, on the basis of dominant lithology, bedding characteristics and structures, grain-size, embedded dropstones and trace/body fossil content. Special attention was also given to the nature of clast size, shape, composition, quality and quantity of matrix. Major lithofacies are:



Compilation of existing geological maps (Garland et al., 1978; Russo et al., 1996). PzT stands for Denticho sand-stone, Pl and Pd are Precambrian. Subhorizontal terrains at the NW and S are Mesozoic and Tertiary. Location of the presented sections is indicated

(a) LFA Breccia-conglomeratic facies: unstratified, very thick unit but heterogeneous in terms of shape, size and composition of clasts. Clasts are dominated by i) angular and sub-angular boulders; and ii) rounded and sub-rounded pebbles and supported by sandy/muddy matrix. Generally it shows white color if supported by siliceous or calcareous cement and dark grey color when supported by mud. Due to presence of iron-oxide cement the unit at places, shows variegated colors particularly maroon, red and yellow. Similarly, presence of silica cement makes it very hard. Presence of big boulders, immature sediment, poor sorting and absence of bedding characteristics supports glacial origin and this litho-facies, and is the main mass of 'tillite' referred in literature. The boulders show significant variation in size and composition and indicate variation in geology at source. It includes- metavolcaniclasts, metavolcanics (both felsic and mafic), metasediments (slate, phyllite and limestone), granite gneisses, granites, gabbros, rhyolites, aplites etc.

Section - IV
Michael Baraka Church Hill
18km east of Wukro Town



Red color thick glacial deposit (LFA) with flame/load structure overlying the basement and underlying LFC

Metavolcanic boulder in red color LFA

(b) LFB Conglomeratic facies: moderately thick unit, characterized by the presence of elliptical, rounded to sub-rounded clasts of boulder and pebble size and sandwiched between sandstone lithologies. Variation in cement provides different colors and hardness to the unit. Elliptical and pointed pebbles are common and some of them show flat broken surfaces possibly due to the load of ice. The matrix of this ‘morainic conglomerate’is generally sandy and layering is often found. Boulders showing homogeneity in size and shape, and heterogeneity in composition suggest glacial origin.

(c) LFC Cross-bedded sandstone facies: white, cross-bedded, calcareous, medium to coarse grained arkosic sandstone. Presence of grit and polymictic conglomerate lenses is common. The unit is also iron-rich muddy at places. It represents braided river deposits. But at the same time, presence of large cross-bedding indicates aeolian influence as well. Presence of textural inversion in petrographic study confirms the view. This is the main litho-facies of typical Enticho Sandstone**.**

(d) LFD Laminated mudstone facies: thinly bedded lacustrine deposits, characterized by thinly laminated ferruginous mudstones, claystones and siltstones. Presence of iron oxide, though poor, provides variegated colors particularly maroon, red and yellow. It suggests low energy depositional environment and at places with well developed ‘varves’. Dropstones are not common in this facies indicating little or no glacial influence in the lake environment. At places this litho-facies is green in colour and very hard if silicified during diagenesis.

(e) LFE Non-laminated mudstone facies: similar to the above but characterized by the presence of dropstones and without laminations. It represents a glacial deposit. This is the main mass called 'glacials' in literature.

(f) LFF Sandy/silty limestone facies: generally thin, rare and occasionally present in thick successions of mudstone. It shows presence of smaller dropstones. It is a good example of fresh water limestone deposition during Paleozoic.

Conclusions

The observations suggest that the Paleozoic successions are the result of repetitions (in space and time) of many episodes of glacial, fluvial and lacustrine sedimentation. Thickness of these litho-facies is primarily controlled by the available accommodation space in the basin. Extent of a particular litho-facies depends upon the prevailing environment at that time. Cross-bedded sandstone facies (LFC) indicate wide-spread fluvial activity and well-developed braided fluvial system in the area. Similarly, LFD suggest well developed small to medium size lakes where the clastic material was supplied by both fluvial and glacial activity. On the other hand, LFA/LFB facies indicate exclusive glacial activity.

Further reading:

Bussert, R. and Schrank, E. (2007). Palynological evidences for a latest Carboniferous-Early Permian glaciation in Northern Ethiopia. Journal of African Earth Science, 49, 201-210.

Bussert, R. (2010). Exhumed erosional landforms of the Late Palaeozoic glaciation in northern Ethiopia: Indicators of ice-flow direction, palaeolandscape and regional ice dynamics. Gondwana Research, 18, 356-369.

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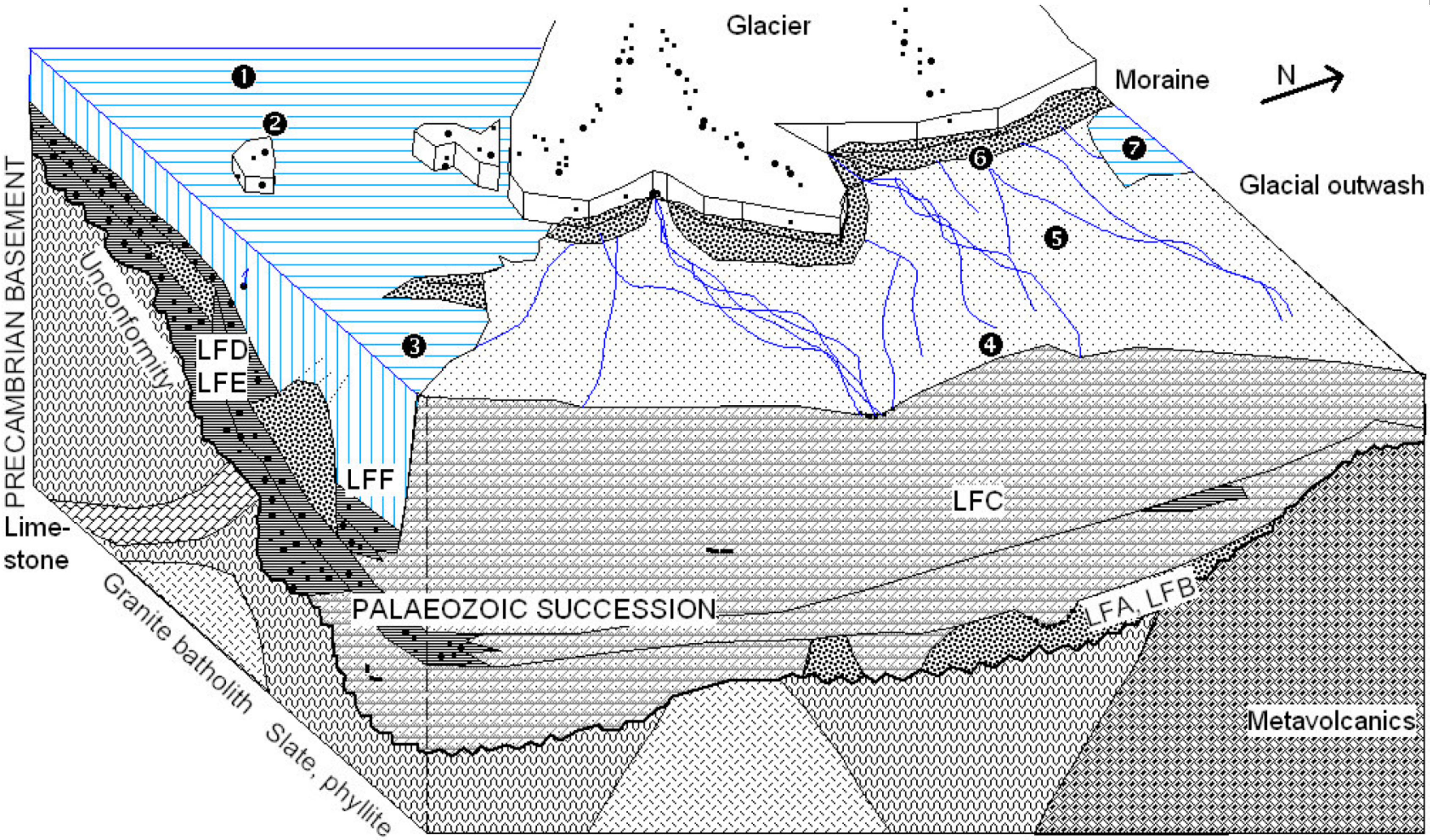
Kumpulainen, R.A., Uchman, A., Woldehaimanot, B., Kreuser, T. And Ghirmay, S (2006). Trace fossil evidence from the Adigrat Sandstone for an Ordovician glaciation in Eritrea, NE Africa. Journal of African Earth Science, 45, 408-420.

Sacchi, R., Alene, M., Barbieri, M., and Conti, A. (2007). On the Paleozoic Tillite of the Adigrat Group (Tigrai, Ethiopia). Periodico di Mineralogia, 76, 2-3, 241-251.



3D glacial model: schematic representation of the study area on an average summer day at the Late Palaeozoicum, with sedimentary lithofacies (LF). Moraines (LFA, LFB), glacial outwash (LFC), and muddy underwater deposits with dropstones (LFD, LFE, LFF) are generated in a glacial environment. Since there were several episodes of advance and retreat of glaciers, the position of the lithofacies changes accordingly. Approximate area covered: 3000 km²; vertical exaggeration: 20 x. Numbers 1-7 correspond to the location of the described profiles. North arrow corresponds to the current context. (Dubey, Bheemalingeswara & Nyssen, 2011)