

Contribution to the Knowledge of the Late Palaeozoic Glaciation in the Republic of Yemen

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Abstract. The grooves, striations, outside clasts, trace fossils and varves found in the Kooli Formation (Permian) in the Republic of Yemen which were considered as an indication of continental glaciation, are re-investigated. It is found that the Kooli Formation was deposited in a glaciolacustrine environment by continental glaciers which were flowing towards the northwest.

Introduction

The gravelly siltstones and silty shales which constitute the lower part of the Kohlan Group in the northern and central parts of the Republic of Yemen (Text-Fig. 1) and which have been formally named as the Kooli Formation [1], (Text-Fig. 2), were considered to be of glacial origin on the basis of the occurrence of tillite (Text-Fig. 3), grooves (Text-Fig. 4), striations (Text-Fig. 5), dropstones (Text-Fig. 6), striated gravels (Text-Fig. 7), outside clasts (Text-Figs. 6 – 8) and varves (Text-Fig. 9), by Roland [2], Kruck and Thiele [3], and El-Nakhal [1, 4]. These authors however, have not interpreted precisely the depositional environment of the Kooli Formation or the direction of the ice flow. Therefore, the exposures of these gravelly fine-grained deposits at Kohlan area are re-investigated and new results are presented. The present study is aimed to discuss these results and their significance.

Stratigraphy

The Kooli Formation displays features normally considered as evidence for the presence of Late Palaeozoic glacial activity in the Republic of Yemen. This rock unit

was introduced by El-Nakhal [1]. It belongs to and constitutes the lower part of the Kohlan Group (Text-Fig. 2). On the basis of its stratigraphical position, the Kooli Formation was assigned to the Permian [1, 3]. In the central regions of the Republic of Yemen, it unconformably overlies the Precambrian basement rocks and is overlain unconformably, by the Early Jurassic Affar Formation.

The Kooli Formation consists of poorly sorted, gravelly, fine-grained sediments which are thinly bedded in their upper part and lack stratification in their lower part. On lithic grounds it was subdivided into two members, the Sharas and the Khalaqah Member [1]. The Sharas Member includes the lower part of the Kooli Formation consisting of unsorted, dark green, silt rich diamicton which is considered as a tillite (Text-Fig. 3). The Khalaqah Member on the other hand, includes the upper part of the formation which consists of thinly laminated gravelly dark green silty shale that may represent annual varves (Text-Fig. 9). The Sharas Siltstone Member includes silty shale intercalations, whereas the Khalaqah Member includes several thin siltstone interbeds (Text-Fig. 9).

Parallel grooves and striations

In the Khalaqah agricultural district (Text-Fig. 1), the upper surface of the Sharas Member is well exposed where parallel grooves (Text-Fig. 4), and striations (Text-Fig. 5) can be traced. Both the grooves and the striations have a northwestern-southeastern trend (Text-Fig. 5) which conforms well with the general orientation of the elongate outside clasts found in the same horizon in the study area (Text-Fig. 8). Exposed individual grooves are up to 5 m long, 30 cm wide and 6 cm deep (Text-Fig. 4).

Kruck and Thiele [3] referred to the occurrence of glacial grooves on the polished surface of the Precambrian basement rocks in the Kohlan area, but they have neither described those grooves nor illustrated them.

Outsize Clasts

Outsize clasts, some of which are striated, are widespread throughout both the Sharas Siltstone and the overlying Khalaqah Silt-Shale Members (Text-Figs. 6–8). At the outcrops of the upper surface of the Sharas Member which consists of silt rich diamicton (Text-Fig. 3), numerous outsize clasts which vary widely in shape and size, are well exposed. Some of these clasts are elongate and show faceted surfaces with two unequally inclined sides (Text-Fig. 8). Measurement of the orientation of the long axis of 30 of these clasts in the Khalaqah district shows that they have a preferred orientation with a NW – SE trend with the gently inclined faceted side dipping towards the SE (Text-Figs 8,10). As mentioned above, this trend conforms well with

that of the grooves and striations recorded in the same horizon in the study area. The tendency of these clasts to have this particular trend is considered as an indication that they have a streamlined orientation in relation to the direction of ice movement so that each clast presents the least resistance [5]. Accordingly, it can be interpreted that the ice in this area was flowing from the gently dipping side towards the steep end of these clasts, i.e. from the southeast to the northwest (Text-Figs. 8,10).

Dropstones

Some of the recorded outside clasts show bending of the laminae at the lower contact (Text-Fig. 6). In most cases, these laminae are deformed by small faults (Text-Fig. 6) which indicates that these structures resulted from the vertical loading and they do not represent flow structures caused by a mobile matrix flowing around the clasts. Therefore, these clasts are considered here as dropstones.

Trace fossils

Trace fossils consisting of biserial arthropod trails are widespread on the laminae of the Khalaqah Member (Text-Fig. 11). These trails are similar to both *Tasmanadia twelvetreesi* Chapman [6], and *Umfolozia sinuosia* Savage [7] which were described from glacial deposits in Tasmania and South Africa, respectively. *T. twelvetreesi* was found in rocks of Late Carboniferous age [8], whereas *U. sinuosia* was recorded from rocks of Permian age [7,9]. As the diagnostic cycle of four pairs of tracks, peculiar to *Umfolozia*, could not be confirmed in the recorded tracks, it is preferred here to assign these tracks to *Tasmanadia twelvetreesi* Chapman. The occurrence of this ichnospecies is considered as additional evidence for the glacial origin of the Khalaqah Silt-Shale Member.

Kruck and Thiele [3] described five types of trace fossils in the study area which they assigned to *Polychaete*, *Permichnium*, *Rhizocorallum*, and *Scolicia*. They compared this assemblage with the trace-fossil association described by Gevers *et al.* [10] in rocks of possible Devonian age, from Antarctica.

Varves

The Khalaqah Member consists of about 90 m of dark green, poorly sorted, thinly bedded, well-laminated, gravelly silty shale with numerous thin siltstone interbeds (Text-Fig. 9). The lamination of this member refers to the occurrence of alternating fine and coarse siltstone laminae which are interpreted as annual varves. Because saline water inhibits the development of well defined diatactic varves [11], the Khalaqah Member almost certainly was inscribed in freshwater. Accordingly, it can be interpreted with a reasonable certainty, that this member was deposited in glaciolacustrine rather than a glaciomarine environment [12], with the probability

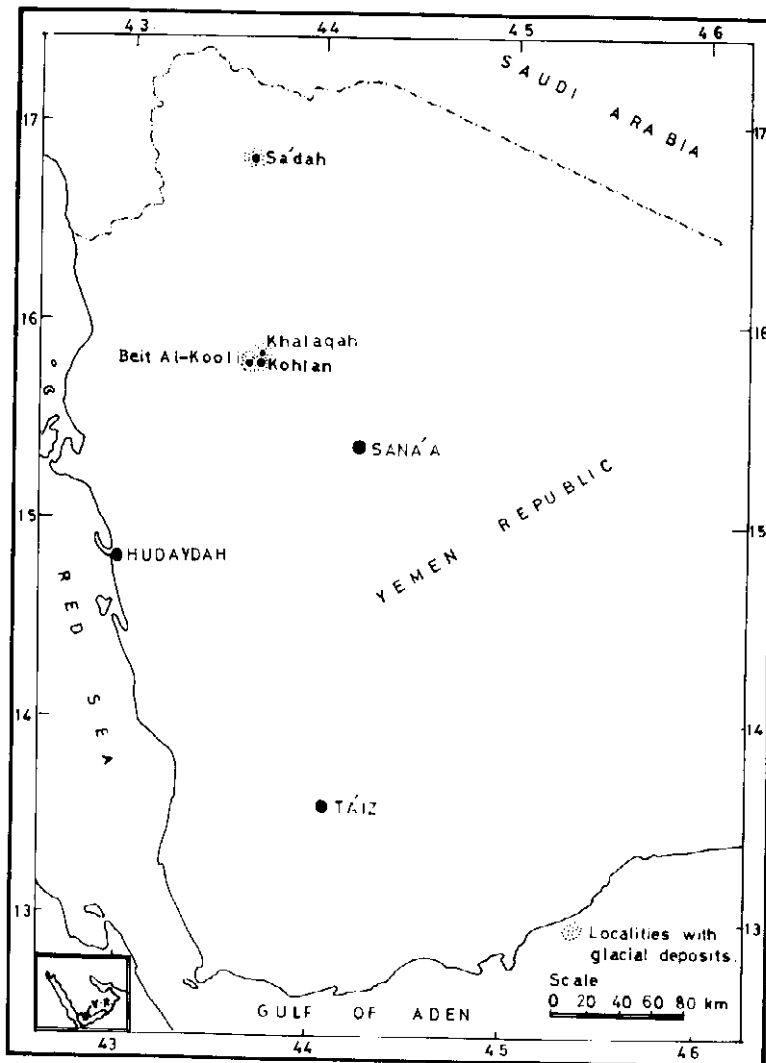


Fig. 1 Location map showing the areas with glacial deposits in the Republic of Yemen. The inset indicates the position of the Republic of Yemen in relation to the Arabian Peninsula.

Age	Group	Formation	Member	Lithology	Characteristics
M.-L. JURAS.	—	AMRAN	—		Limestone
TRIASSIC? — EARLY JURASSIC	K O H L A N	Alfar	Hessan Ss.		Light colored sandstone (75 m)
			Souq Ss.		Ferruginous sandstone (60 m)
			Azzan Ss.		Light colored sandstone (55 m)
P E R M I A N	K	Kooti	Khalaqah Shale		Silt-shale and siltstone interbeds (90 m)
			Sharas Siltstone		Siltstone and silt-shale (16 m)
PRE-CAMB.	—	—	—	XXXXX XXXXX XXXXX	Basement rocks

Fig. 2. Lithostratigraphic subdivison of the Kohlan Group in the Republic of Yemen (after El-Nakhal, 1).



Fig. 3. Exposure of the upper surface of the tillite of the Sharas Member; Beit al-Kooli village (after El-Nakhal, [4]).



Fig. 4. Parallel grooves on the upper surface of the Sharas Member, the rock hammer crosses two grooves; Khalaqah district.

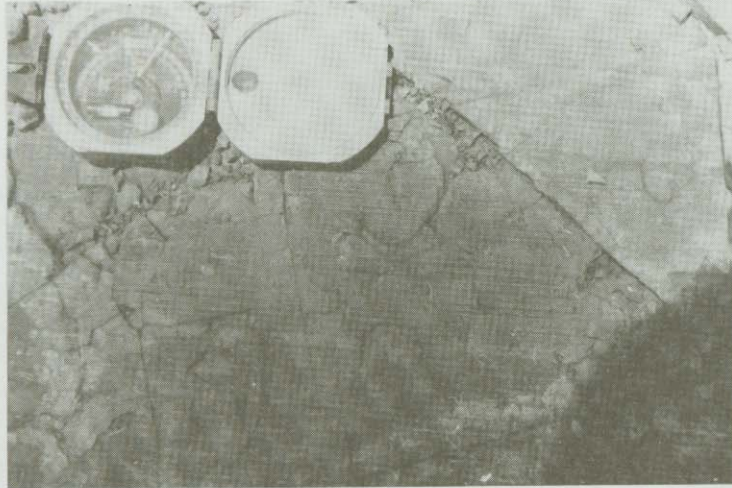


Fig. 5. Parallel striations on the polished upper surface of the Sharas Member; Khalaqah district.

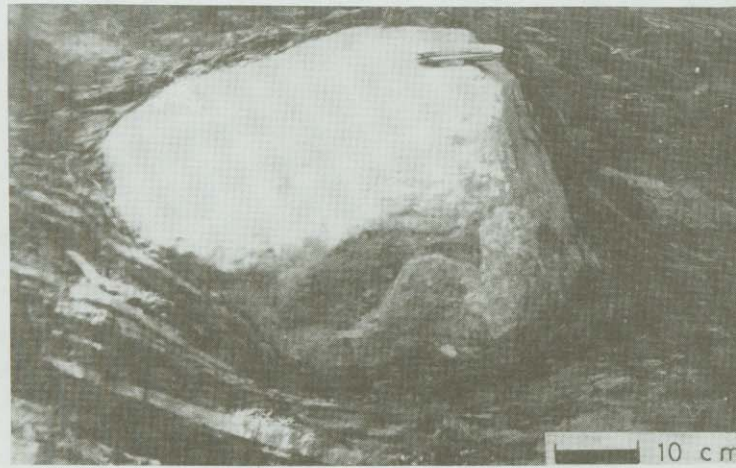


Fig. 6. Dropstone in the rhythmically laminated Khalaqah Member showing bending of laminae at the lower contact; a small fault appears near the lower right corner; Kohlan al-Souq.

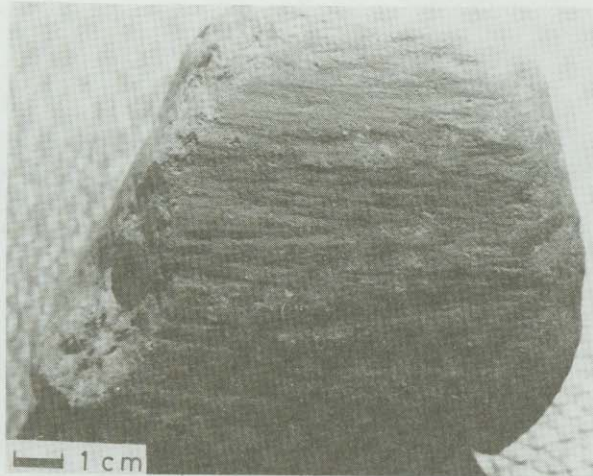


Fig. 7. Striated cobble from the Sharas Member, Beit al-Kooli village.



Fig. 8. Elongate boulder which is morphometrically asymmetrical along the long axis; Khalaqah district. Photograph taken looking towards the northeast.

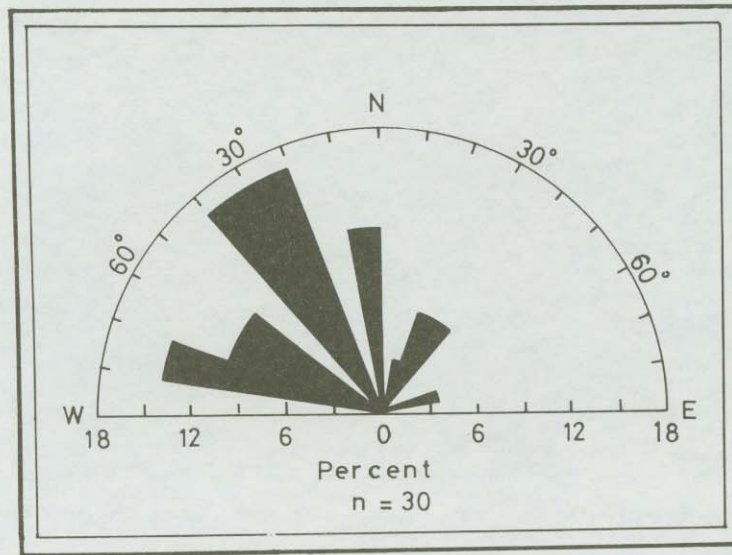


Fig. 9. Hemispherical histogram showing long-axis orientation of the outsize clasts which have two unequally sloping sides exposed at the upper part of the tillite of the Sharas Member; Khalaqah district. The measured trends show the direction from the gently sloping side towards the steep side of the studied clasts.

that it is partly composed of debris of flows of paraglacial origin. In view of the fact that stratification of sediment may be destroyed by organisms that feed on organic matter contained in bottom muds, the preservation of lamination indicates either very rapid deposition or toxic bottom conditions and suppression of benthic fauna [11]. However, as mentioned above, trace fossils are widespread throughout the Kooli Formation which indicates that the bottom conditions under which this formation was deposited were not toxic. Accordingly, the preservation of lamination in the Kooli Formation is attributed to very rapid deposition.

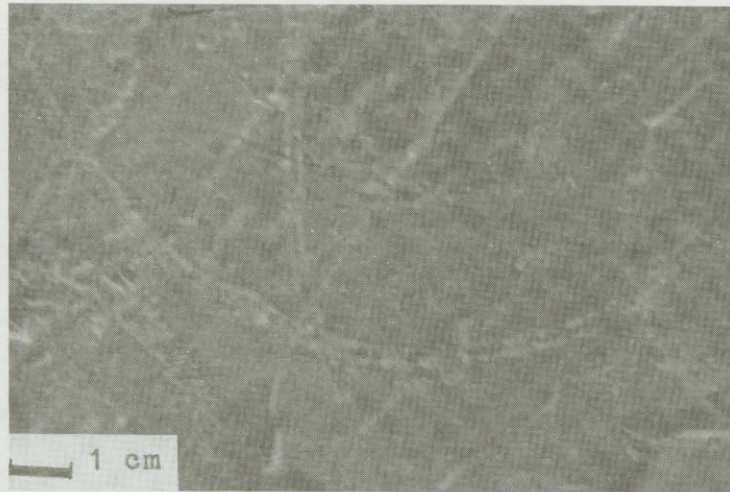


Fig.10. Trackways of *Tasmanadia twelvetreesi* Chapman, on the lower surface of the varves of the Khalaqah Silt-Shale Member; Kohlan al-Souq.

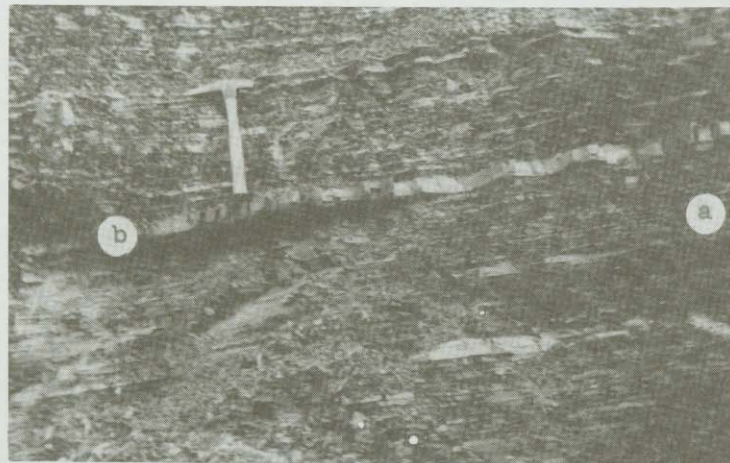


Fig.11. Section through the rhythmically laminated Khalaqah Silt-Shale Member showing varves (a), and a thin siltstone interbed (b); Kohlan al-Souq.

Summary and Conclusions

The study of the grooves, striations, outsize clasts, trace fossils, and varves found in the Permian Kooli Formation in the Kohlan area, has led to the following conclusions:

- a. The trend of the grooves, striations and the elongate outside clasts which are morphometrically asymmetrical along the long axis, suggest that the ice was flowing from the southeast to the northwest.
- b. The preservation of the varves indicates that the Kooli Formation accumulated in freshwater and it was deposited in glaciolacustrine environment.
- c. The abundance of *Tasmanadia*-style trace fossils indicates that the bottom conditions were not toxic, and supports the glacial origin of the Kooli Formation.
- d. Preservation of the varves accompanied by the abundance of the trace fossils, indicates that the deposition of the Kooli Formation was rapid.

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References

- [1] El-Nakhal, H.A. "A Lithostratigraphic Subdivision of Kohlan Group in Yemen Arab Republic." *Iraqi Journal of Science*, 28 (1987), 149-180.
- [2] Roland, N.W. "Jungpalaeozoische Glazialsuren auf dem Arabischen Schild." *Eiszeitler und Gegenwart*, 28 (1978), 133-138.
- [3] Kruck, W. and Thiele, J. "Late Palaeozoic Glacial Deposits in the Yemen Arab Republic." *Geologisches Jahrbuch*, 46 (1983), 3-29.
- [4] El-Nakhal, H.A. "Possible Late Palaeozoic Glaciation in the Central Parts of the Yemen Arab Republic." *Journal of Glaciology*, 30 (1984), 126-128.
- [5] Rose, J. "Glacier Stress Patterns and Sediment Transfer Associated with the Formation of Suprimposed Flutes." *Sedimentary Geology*, 62 (1989), 151-174.
- [6] Chapman, F. "On Some Remarkable Annelid Remains from the Arthur River, N.W. Tasmania." *Royal Soc. Tasmania, Papers and Proc. for 1928, (1929)*, 1-5.
- [7] Savage, N.M. "A Varvite Ichnocoenosis from Dwyka Series in Natal." *Lethaia*, 4 (1971), 217-233.
- [8] Glaessner, M.F. "Paleozoic Arthropod Trails from Australia." *Palaontologische Zeitschrift*, 33 (1957), 103-109.
- [9] Anderson, A.M. "The *Umfolozia* Arthropod Trackway in the Permian Dwyka and Ecca Series of South Africa." *Journal of Paleontology*, 55 (1981), 84-108.
- [10] Gevers, T.W. *et al.* "Trace Fossils in the Lower Beacon Sediments (Devonian), Darwin Mountains, Southern Victoria Land, Antarctica." *Journal of Paleontology*, 45 (1971), 81-94.
- [11] Pettijohn, E.J. *Sedimentary Rocks*, 3rd Ed. New York: Harper and Row, 1975.
- [12] Sauramo, M. "Studies on the Quaternary Varve Sediments in Southern Finland." *Finland, Commission Géol. Bull.* 60 (1923), 1-164.

إضافة للمعرفة عن الفترة الجليدية التابعة لحقب الحياة القديمة
التأخرة في الجمهورية اليمنية
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ملخص البحث. أعيدت دراسة الميازيب والحدوش والفتات ذو الأحجام الزائدة وآثار الأحافير والرقائق الموجودة في متكون الكولي (العصر البرمي) في الجمهورية اليمنية، والتي أعتبرت دليلاً على وجود فترة جليدية قارية. وقد وُجد أن متكون الكولي قد ترسب في بحيرة جليدية بمثلج قارية كانت تتحرك نحو الشمال الغربي.