Medial Moraines of Valley Glaciers and the Surviving Ice-Marginal Landforms

With 19 Figures

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Summary – Medial moraines form significant patterns of parallel lines from surficial debris on recent valley glaciers. Currently it is debated whether deposits of these moraines survive as remnants in the landscape after glacier recession. After broadly characterizing such moraines, and to document their actual existence, a set of Google Earth satellite images of glaciers on three continents illustrates ice-marginal sediments of medial moraines. The features originate mainly from the Little Ice Age. The interpretation of similar Ice Age landforms of quite different sizes as features homologous to former medial moraines seems to be very probable. As an Ice Age example of largest format, the Danish island of Langeland is being considered as the terminus of a medial moraine from central southern Norway at the maximal extension of the last ice advance from this region.

Zusammenfassung – Mittelmoränen formen auf Talgletschern signifikante Muster paralleler Linien aus Oberflächenschutt. Gegenwärtig wird diskutiert, ob diese Moränen nach einem Gletscherrückzug als Restformen im ehemaligen Vereisungsgebiet überleben. Nach einer Charakterisierung dieser Moränen und um ihre aktuelle Existenz zu dokumentieren werden Google Earth Satellitenbilder von Gletschern aus drei Kontinenten mit diesen Eisrandsedimenten vorgestellt, die überwiegend aus der holozänen „Kleinen Eiszeit“ (Little Ice Age) stammen. Als homologe Erscheinungen jüngerer Mittelmoränen erscheint die Interpretation ähnlicher Formen erheblich größerer Dimensionen aus dem pleistozänen Eiszeitalter naheliegend. Daher kann die dänische Insel Langeland als Endabschnitt einer Mittelmoräne aus dem Hochland Südnorwegens und Zeugnis der maximalen Ausdehnung des letztglazialen Eises dieser Region interpretiert werden.

Key Words: Glaciers; Medial Moraines; Ice Age; Drumlins; Langeland; Ice-Marginal Landforms

1 Introduction

Medial moraines are characteristic features of systems of modern valley glaciers (Fig. 1). They are surface features of the ice and are absent from ice fields without overtopping mountains. Each individual glacier in its catchment area receives some surficial debris by lateral rock falls and rockslides from overtopping peaks or mountains. This material forms the lateral moraines of glaciers. The merging of two "parent" glaciers creates one medial moraine from the two inner lateral moraines. The medial moraine moves with the flow velocity of the ice as a significant debris conveyor belt without sorting of the debris. Under debate is whether distinctive accumulations or landforms are created under this scenario.

Based on GOOGLE EARTH satellite images, our paper considers the questions (a) how medial moraines on modern glaciers in mountains on three continents act, and (b) whether they can leave distinctive morphological accumulations of surface debris from the younger past. The relevant period is the "Little Ice Age", which with oscillations lasted for about 500 years and ended in the 19th century. During this time interval, the glaciers exhibited the highest and farthest extensions of the last several thousand years. From the observed behavior of modern medial moraines and their visible landforms, comparisons are drawn to Ice Age features in the pre-alpine landscape. As a presumed Ice Age example of largest dimension, the Danish island of Langeland is discussed.

Fig. 1. Schematic compound ice-stream with numerous individual glaciers. Only the strongest form the ice-stream's snout, while smaller glaciers end marginally or between larger ones. Like each individual glacier, each medial moraine keeps its own character. All these moraines reach the ice margin, either at the glacier's snout, or laterally, or at a nunatak (a rocky island in the ice), and deposit their debris there. A medial moraine can change into a secondary lateral moraine. (Graphics: ANDRÉ MICHEL; from WAGNER, 2014, Fig. 2).

This figure illustrates a dynamic system: During an equilibrium stage (called stadium), the glacier´s snout remains at the same place while the ice continues to move forward. The debris of a moraine is deposited at the same place successively and can build up significant morphological structures during a stadium.

B – ice margin without debris cover; E – terminus of smaller lateral and medial glaciers; FD – fluvio-glacial deposits. Gravel bed as washout of moraine debris; Lp – original (primary) lateral moraine. A *lateral moraine* is the term for marginal debris still on ice and moving with it. A definite debris deposit at a glacier´s lateral margin is a *border moraine*.; Ls – secondary lateral moraine formed by a stranded medial moraine; MA – starting point of medial moraine type A: the parental glaciers merge below the equilibrium line; MB – starting point of medial moraine type B: the parental glaciers merge above the equilibrium line; MN – medial moraine ends at a nunatak (rock island in ice); Mt –medial moraine ending terminally; O1 – laterally stranding point of a medial moraine; Os – laterally stranding point of a medial moraine, which is transformed into a secondary lateral moraine (Ls); T – strand built by divers merged medial moraines; U – merging point of two medial moraines.

2 Material and Methods: General aspects of medial moraines (compare Fig. 1)

Number and debris content

A glacier system formed by **n** individual glaciers contains **n** -1 medial moraines, and each of them carries debris from two former lateral moraines. By this process in a compound ice stream, most of the lateral surface debris is transferred into medial moraine debris, and only the outer lateral moraines from the two outermost original glaciers will remain lateral.

Two types

Depending on the source areas, two types of medial moraines are recognized:

Type A: Medial moraines occurring below the equilibrium level of the parental glaciers involved are supraglacial moraines and therefore are visible along their entire length (Figs. 2, 4, 5, 6). EYLES and ROGERSON (1978) named them *“ice-stream interaction medial moraines”.*

Type B: With a merging point of the two parental glaciers above the equilibrium level, the medial moraine *in statu nascendi* is covered by annual snow and firn and starts invisibly as an intraglacial moraine (Figs. 7, 8). By the ablation processes at lower elevation, however, the moraine becomes visible as a superficial debris line like a medial moraine of Type A. The actual starting point is usually detectable by the topography of the ice discharge areas. EYLES and ROGERSON (1978) named them *“ablation dominant medial moraines”*. Medial moraines of type B may contain some debris from the glacier base, but this seems to be unimportant according to RÖTHLISBERGER (1967) and HABBE (1996).

Rise and widening toward the terminus

In summertime, ablation of ice can reach several cm/day. As the debris of the medial moraines shades their ice, the moraines gradually rise above the glacier´s general surface. The elevation may lead debris sliding from the moraine ridges. Further, connected with the slowing of glacier movement toward its end and the resulting congesting debris transport, medial moraines often exhibit a significant widening (Figs. 7, 9, 10, 11, 17). With several medial moraines merged, debris may completely cover a glacier tongue (Fig. 2, 14).

Individuality of tributary glaciers in an ice stream

In contrast to flowing water, ice masses of glaciers do not mix but keep their individuality within an ice stream. Thus, the single tributary glaciers of an ice stream may show a very different character by, e.g., the rock types from their source valleys. Further, only the most powerful of the tributary glaciers reach the end of the ice stream, whereas smaller ones end early at the margin or within the complex ice mass (Fig. 2, 14, 17). Often, several medial moraines unite in one track (Figs. 4, 5). All reach somewhere the margin of the glacier, either earlier along its side or later at its snout. Those medial moraines, which end marginally, turn into lateral moraines, here being called 'secondary lateral moraines'.

Secondary lateral moraines

In the terminal part of a glacier complex, a medial moraine often ends up at the glacier's side, and continues as a new (secondary) lateral moraine (Figs. 5, 7, 14, 17). These moraines obviously contain rocks from two primary lateral moraines. Furthermore, in a secondary lateral moraine, rocks from the right slope of a glacier may move to the left slope of the next (and probably larger) glacier, or vice versa. Such events happened on a large scale in the Ice Age along the Rhone Glacier in Switzerland.

Medial moraines as conveyor belts for debris

Where a medial moraine reaches the ice margin – either at the side or the tip of the glacier´s snout – the ice base disappears but the debris remains. If the ice margin stays at the same place for a certain time as during an equilibrium stage (a stadium), the moraine each year will deposit the debris of a one year flow. This process may produce characteristic forms of lasting lateral or terminal moraines (Figs. 2, 4, 6-12, 14, 16, 18). In an advancing glacier, the amount of debris of one year's flow minus the mass of the length of advance is deposited and covered by advancing ice. That process converts original surface moraine into ground moraine. In contrast, if ablation is stronger than the glacier's advance, the amount of moraine deposits will rise the mass delivered by a one year's flow plus that of the distance of ice retreat. If the retreat is slow enough, an elongated ridge of debris piles up (Figs. 4, 9, 12). Its survival depends – as that of all deposits in front of a glacier – on its mass and its distribution and the erosional power of meltwater. If the ice margin oscillates more quickly, debris will distribute over a wider area and after glacial retreat remains insignificant. So, these general processes depend on the dynamics of glacier movement and exhibit many variations from place to place.

Landforms at the origin of medial moraines

A medial moraine may leave permanent structures not only at its end but also at its origin. At the confluence point of two glaciers, by chance a part of the debris of the two lateral moraines may accumulate but does not connect with the starting medial moraine. This results in Y-shaped moraine structures (Figs. 5, 13).

3 Results

3.1 Examples of modern glaciers with medial moraines and ice-marginal landforms

Inland ice covering the relief as in most regions of Greenland has no surficial debris and therefore no medial moraines. These regions are not of concern here. There are, however, and apart from the Alps, in the Arctic, Caucasus, Himalaya, Sikkim, Tibet and the Pamir, New Zealand, and other areas many examples of valley glaciers of the alpine type with medial moraines of both types. The following figures relate to several recent glacier types and show manifold medial moraines and their movement on ice. Less significant but important for our arguments and partly highlighted by arrows in the photographs are accumulations outside of areas not covered by ice anymore and left by medial moraines at places where they reached the glacier's margins. Even if these ridges may contain dead ice, they are too conspicuous to disappear if all dead ice inside is melted. The structures mostly are longitudinal and point in the direction of the flow of the glaciers, or are parallel to their margins. They were formed most likely during the Little Ice Age, which lasted from approximately 1300 to 1900 AD. Within this time frame, advance and retreat of the glaciers were rather balanced and the ice margins maintained similar positions. The time span evidently was long enough to accumulate clearly medial moraine landforms even if the thickness of the debris cover on the glaciers was modest.

Fig. 2. Baffin Island, at approximately 66°24'N and 63°17'W (scene 15 km wide). The ice stream is composed of 12 tributary glaciers with 11 medial moraines. Those ending successively at the glacier's margins have formed shorter and longer border moraine ridges (framed) in the Little Ice Age. Elongated terminal deposits of the medial moraines ending at the glacier snout are recognizable down-valley (Credit: GOOGLE EARTH, 22.7.2006).

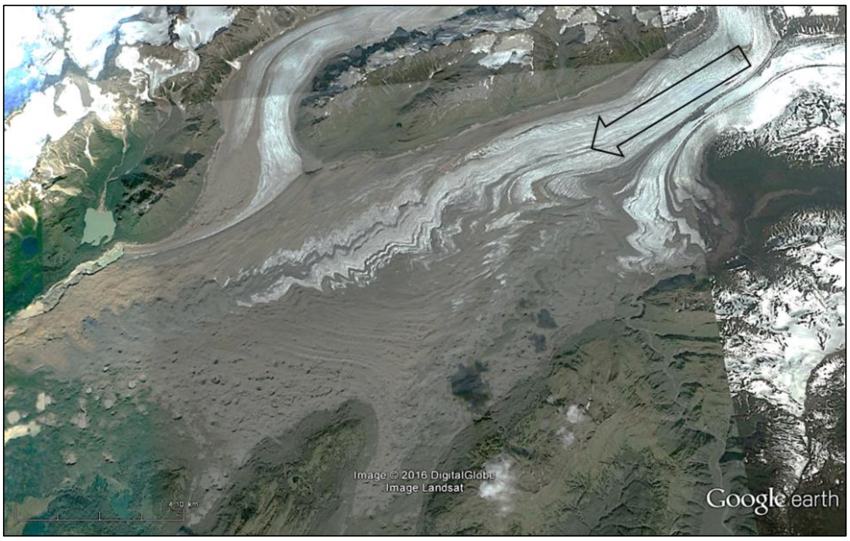

Fig. 3. Wrangell-St. Elias Mountain Range, Alaska, at approx. 60°29'N and 144° 03'W (scene 25 km wide). The glacier's snout is nearly covered by merged medial moraines, and is finally hidden by debris. This forms a large end moraine in front of the glacier's snout. Bending of the medial moraines on the glacier from the right is most likely the result of a glacier surge triggered by an earthquake. (Credit: GOOGLE EARTH, 7.9.2014)

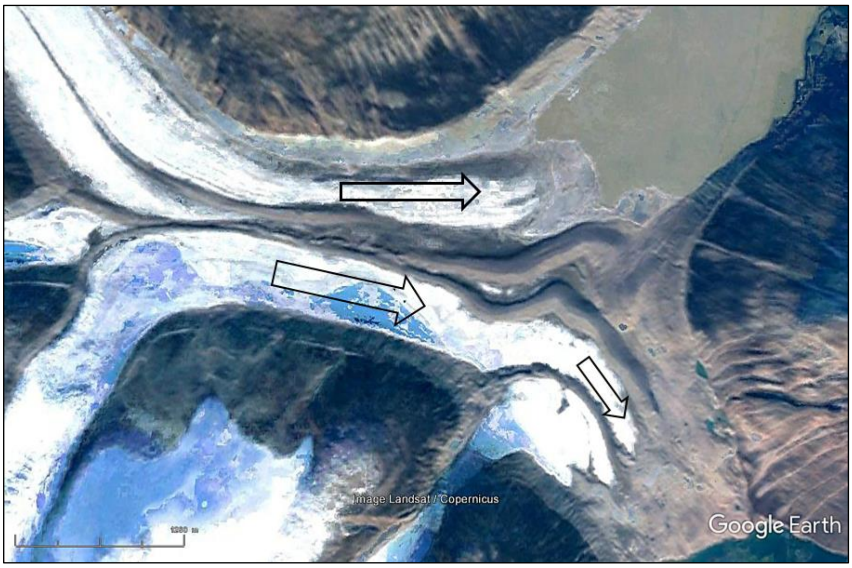

Fig. 4. Baffin Island, 70°38´'N and 71°39´'W (scene 7 km wide). Three medial moraines combine to one strand but keep their identity and separate again toward their ends. Each forms conspicuous longitudinal deposits at their ends. (Credit: GOOGLE EARTH, 18.4.2005).

Fig. 5. Southern Yukon Territory, Canada, at about 59°43'N and 137°33'W (scene about 8 km wide). The medial moraine ML merges with several other moraines and turns into the secondary lateral moraine Ss. Finally, it merges with the central medial moraine Mz, and together they form the continuous terminal moraine E. The narrow northern medial moraines run further down-valley. (Credit: GOOGLE EARTH, 7.9. 2014).

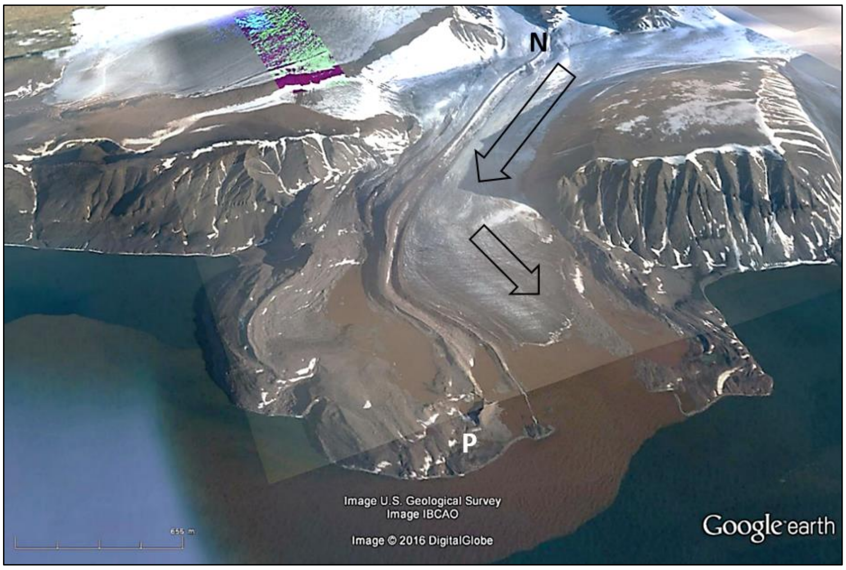

Fig. 6. NW Greenland at 77°23'N and 71°37'W (scene about 5 km wide). Basal, lateral and terminal morainic debris of the glacier have built up in course of the Pleistocene a conspiciuous delta-like accumulation in the sea. The narrow medial moraine starting at the nunatak N left, in the Little Ice Age, at its end an about 2.5 km long series of punctual landforms P. (Credit: GOOGLE EARTH, 1.7.2012).

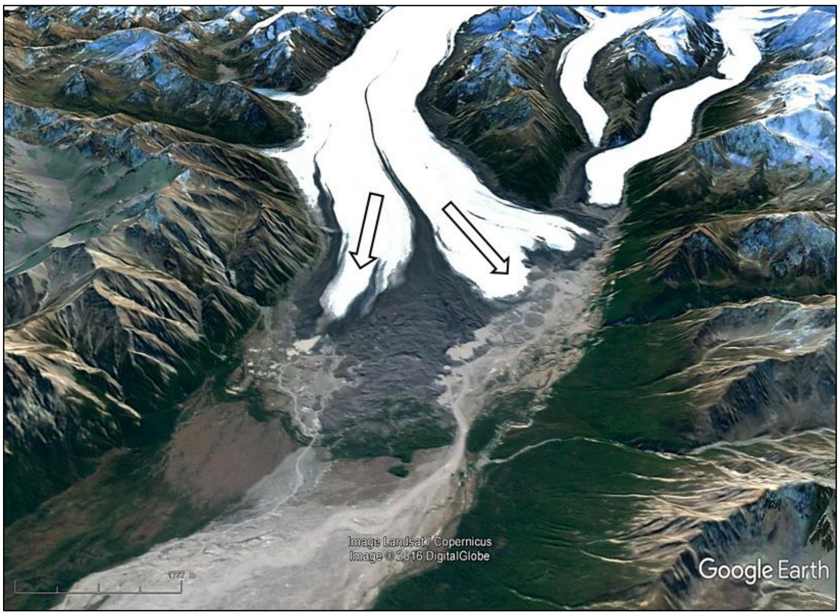

Fig. 7. Nelchina Glacier, Alaska, at 61°43'N and 147°03'W. The glacier exhibits two medial moraines type B, which became visible only on the 5.5 km wide glacier tongue. The strongly widened central medial moraine left a broad accumulation of the hummocky-moraine type during the Little Ice Age. The orographic right-hand medial moraine runs to the glacier´s margin and forms a secondary lateral moraine. (Credit: GOOGLE EARTH, 11.8.2005).

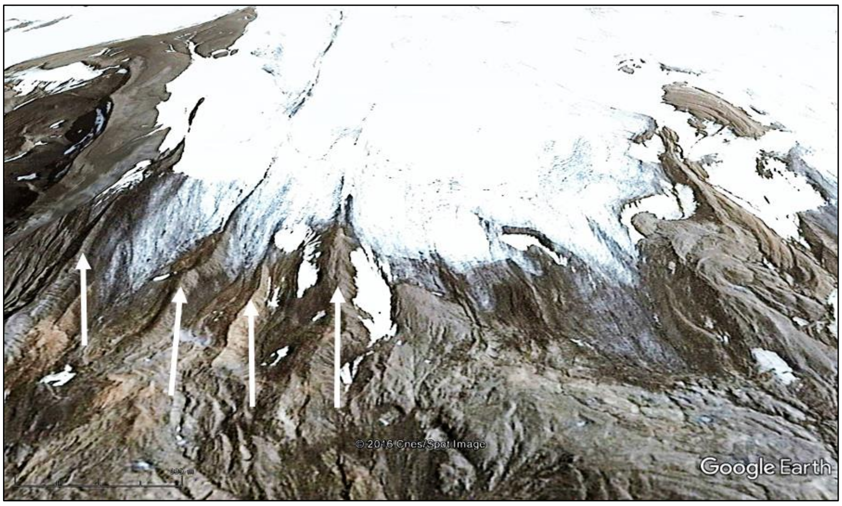

Fig. 8. Bardabunga region of Vatnajökull, Iceland, at 64°39'N and 17°39'W (scene about 3 km wide). The image shows several narrow medial moraines first occurring near the glacier's snout. Their terminal accumulations exhibit the typical wedge-like widened longitudinal shape. (Credit: GOOGLE EARTH, 21.6.2015).

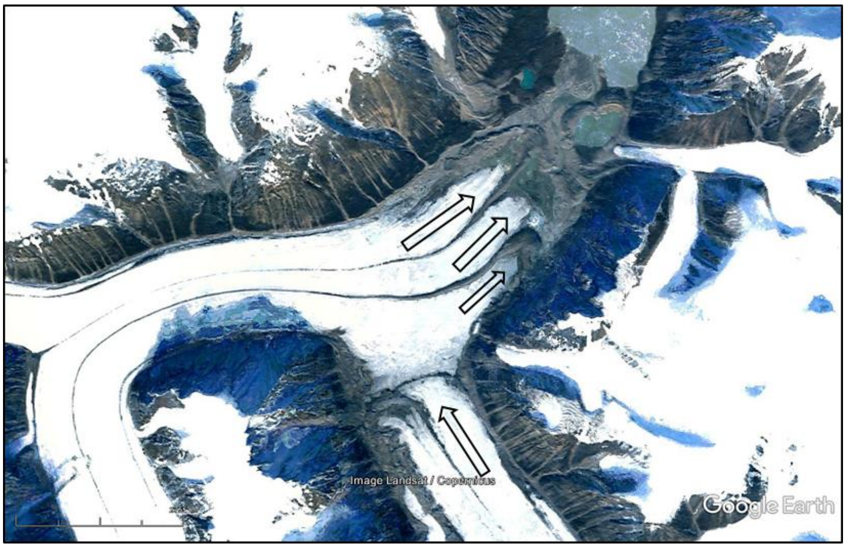

Fig. 9. Northern part of Baffin Island, Canadian High Arctic, at about 72°21'N and 76°28'W (scene about 10 km wide). The two medial moraines, widening to their ends, are building up conspicuous final accumulations. Landforms of different types from the Little Ice Age are recognizable on the glaciers apron. (Credit: GOOGLE EARTH, 2002).

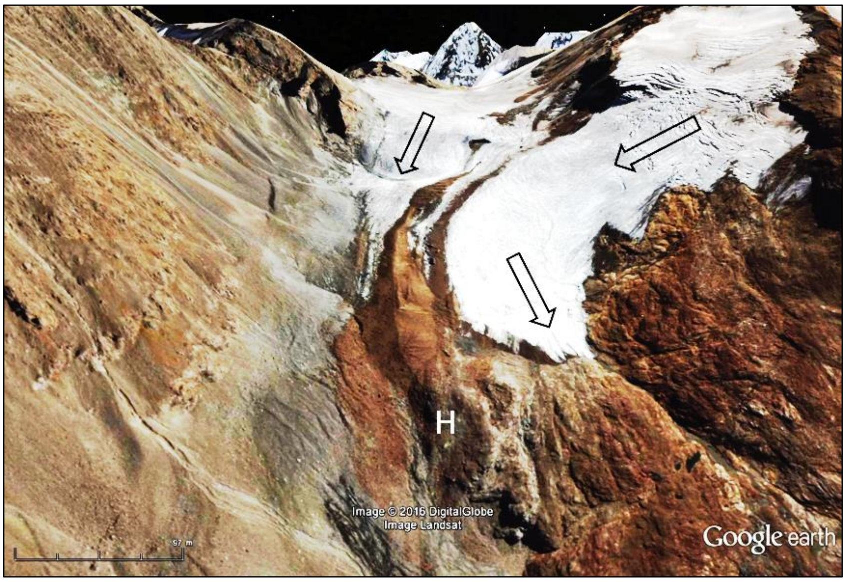

Fig. 10. Northern slope of Caucasus west of Dombai at approximately 43°18'N and 41°30'E. A glacier with a 300 m wide tongue. Both medial moraines unite and have formed at their end a broad hummocky moraine field (H). (Credit: GOOGLE EARTH, 17.9.2012).

Fig. 11. SW Greenland at about 66°10'N and 49°45'W with a 1.1 km wide glacier snout. The medial moraine exhibits a wedge-like widening at its end and delivers its debris to a terminal moraine. (Credit: GOOGLE EARTH, 4.9.2012).

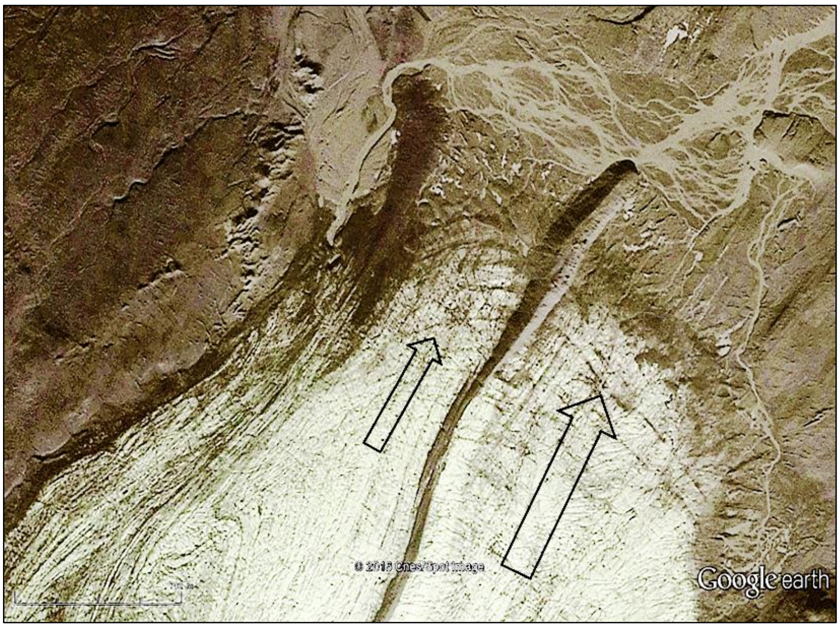

Fig. 12. Eyjabakkajökull glacier, Iceland, north-eastern section of Vatnajökull at 64°42'N and 15°33'W. Two medial moraines each left a 600 m long narrow accumulation (Credit: GOOGLE EARTH, 7.8.2013).

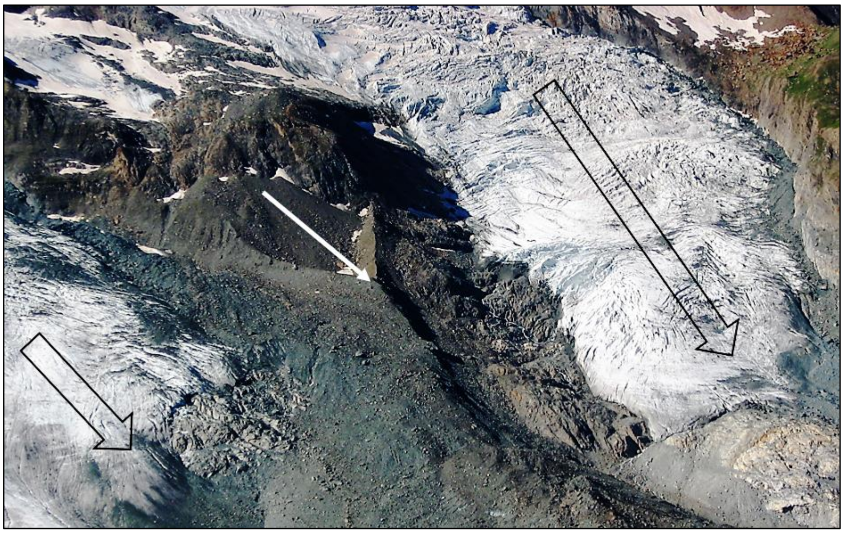

Fig. 13. Gorner Glacier complex in the Wallis Alps, Switzerland at 45°57' N and 7°46' E (scene about 1,200 m wide). From the point where in the Little Ice Age the two glaciers met (indicated by an arrow), the two lateral moraines left behind a Y-shaped structure from the debris, which was not moved away by the active glaciers. (Credit of photo: G. WAGNER, 2013).

Fig. 14. West Fork Glacier in the eastern section of Denali, Alaska, at 63°17’N and 150°08’W (scene about 10 km wide). Very long ridges of medial moraines on the glacier and on its apron show meandering patterns, most likely originating from a glacier surge triggered by an earthquake. It is not possible to deduce from the image how far moving or stagnant ice under the debris cover reaches down-valley. (Credit: GOOGLE EARTH: 3.8.2004).

Fig. 15. Allalin region, Wallis, Switzerland at 46°03’N and 7°57’E. In the center a 1000 m long medial moraine from the Little Ice Age, developed between the Allalin glacier (its modern front at left and above), and the Hohlaub glacier (out of picture). In the right section of the image is seen the left border moraine of the Hohlaub glacier (Credit of photo: G. WAGNER, 2015)

Fig. 16. Near Eidam Bay, Spitsbergen (Norway) at 78°24’N and 12°52’E. This well-developed elongated medial moraine structure originates from two lateral moraines, which again occur separated on a length of 1000 m toward their ends on the apron of the glacier. (Credit: GOOGLE EARTH, 5.8.2011).

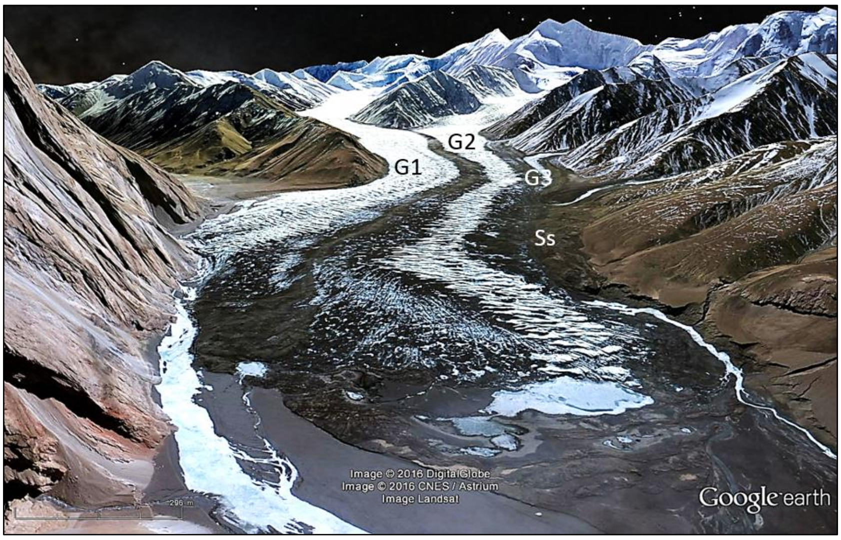

Fig. 17. The Singhi Glacier, SW China at 35°44'N and 76°59'E with an about 2 km wide tongue. The medial moraine between ice streams G1 and G2 is visible on its entire length. Its debris cover is rather thin, its sediments washed out and distributed widely by meltwaters. In front of the glacier, the medial moraine between ice streams G2 and G3 is transformed into the secondary lateral moraine Ss. The right side of G1 exhibits no significant lateral moraine. (Credit: GOOGLE EARTH, 27.10.2014).

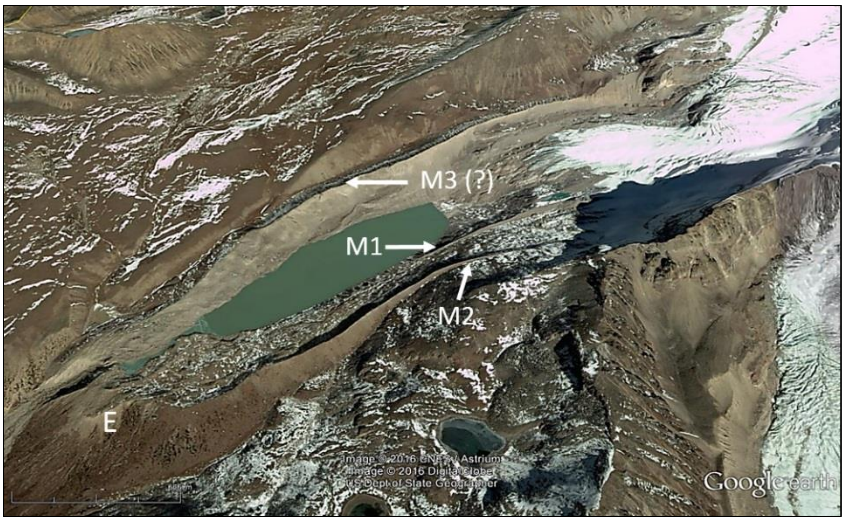

Fig. 18. Apron of a small glacier SW of Chomo Yummo summit in Sikkim (Himalaya) at 28°00'N and 88°30'E (scene about 4 km wide). The strongly receding glacier was originally composed of three main ice lobes with two medial moraines M1 and M2. They have built up at their end the conspicuous terminal moraine E. If below the high slope along the right side of the main glacier another narrow ice lobe existed, M3 (?) may represent another medial moraine. To clarify the situation a field inspections seems to be necessary. (Credit: GOOGLE EARTH, 3.12.2014).

3.2 The Langeland Island (Denmark) as a presumed Ice Age medial moraine

By its shape alone, Langeland, in the Great Belt (Storebaelt) between Lolland and Fyn in Denmark is special. While almost all Danish islands exhibit irregular contours since the postglacial transgression, Langeland appears as regular by its clear N-S direction (199°) with an overall length of 51 km. It widens from 3 km in the north to about 8 km in the south. Moreover, its unusual surface features are remarkable (Fig. 19).

Ehlers (2011) describes the island as follows (translated from German by the authors): *"The relief of Langeland Island is special because of a large number of conspicuous hills. Their heights range from a few up to 37 m, with round or oval shapes and diameters of 50 to 300 m. The Danish name is "hatbakker" (hat-like hills.) SMED (1962) counted about 1,200 on Langeland alone and mentioned, that they mostly consist of stratified material, which is partly significantly tilted, so that the strata often are nearly perpendicular. The strike is parallel to the lines of the hills. Similar features are observed in other parts of Denmark where, however, not as concentrated. In the literature, the hatbakker are called "dislocated kames" (i.e., dislocated subglacial formations) and it is assumed that perturbations by Baltic glaciers played a role in their genesis. MILTHERS (1959) concluded that the hatbakker were squeezed from the east-southeast."*

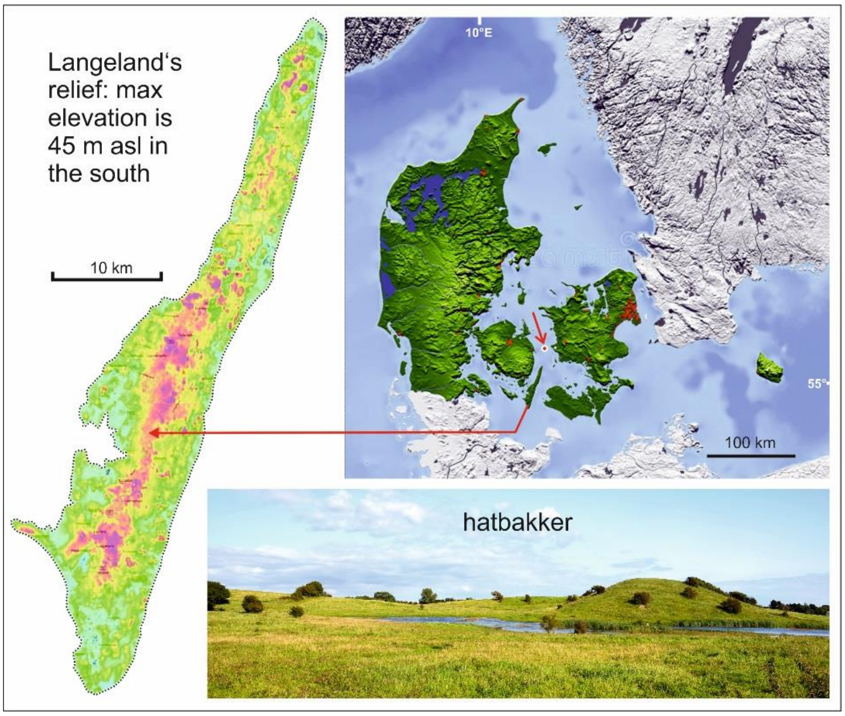

Fig. 19. The 51 km long island of Langeland in the southern Storebaelt (Great Belt), the widest channel between North Sea /Kattegat and the Baltic Sea. Its backbone is a line of round or oval hills with very similar hat-like forms, called "hatbakker" in Danish. This line is supposed to be a medial moraine left from the last ice advance from southern Norway and subsequently affected later by Baltic ice from east-southeasterly direction (Credits: www.topographic-map.com, www.dreamtime.com, Photo: A. Hager)

This characterization of Langeland – besides the geomorphology – only concerns sediment types and genesis of the long belt of hatbakkers. The question which mechanisms has moved the enormous mass of material including gravel – doubtlessly over large distances – is not considered. In relation to their origin, it is only mentioned, that they rest on young Baltic basal moraine. The medial moraine hypothesis, however, starts at a principally new point: While it keeps all possibilities of local sedimentation open, it discusses the question of a former long distance transport as well as the source of the material.

It seems clear that the moraine structures of Langeland belong to the last phases of the last ice age. Based on the younger and summarizing literature combined with dating (HOEMARK-NIELSEN 2007; HOEMARK-NIELSEN *et al.* 2012; SMED (2014); STROEVEN *et al.* 2016), the Storebaelt Glacier from southern Norway receeded from the Langeland area close to 20,000 BP while the last advance of the Baltic glacier from ESE happened, which in turn receeded between about 18,000 – 17,000 BP. For a location in the southern part of the island an exposure age of 16,400 ± 900 y using the beryllium 10-method was found.

Towards the final phase of the last ice age, the now 2,200 to 2,500 m high peaks in Jotunheimen and Dovre of southern Norway must have surmounted the ice shield as nunataks. They delivered the debris from weathering of the peaks fallen onto the firn (most probably above the equilibrium line) from which medial moraines were developed. These moraines became epi- or intra-glacial conveyor belts and were moved – on the ice or in its interior – over any distances. Each medial moraine finally reached an ice margin and left their debris. The existence of such deposits at the fringe of last stages of Scandivian glaciers has to be postulated from the glacier dynamics alone.

Our proposal that the structure of the island of Langeland is a large accumulation by a medial moraine, is based on three reasons. (1) The long axis of the island as well as those of the lines of single hills point to a direction of ice flow from southern Norway. (2) Looking south, the island widens, rises and ends with steep frontal slopes. (3) From sand grains to large boulders, all types of stratified and un-stratified near-ice accumulations occur. The three features are signatures of medial moraines as in the alpine forelands. Similar structures are recognizable in our Figs. 8–12.

An additional remarkable structure is the isolated, originally 25 m high moraine hill of the isle of Sprogö in the middle of the Storebaelt (Great Belt), being in the upstream extrapolation of Langeland's long axis. In our view, the only explanation for its existence is a terminal accumulation of a medial moraine, probably deposited by a short stop during the ice recession from Langeland.

The medial moraine hypothesis for Langeland exclusively deals with the long-distance transport of the debris. Of course, all kinds of sediments are possible at the end of a large medial moraine**,** due to the chaotic interplay of ice, debris and meltwaters, like in non-stratified moraines, eskers, kames and fluvio-glacial gravel. Therefore, the statements of EHLERS (2011) and other authors related to the sediments forming the enigmatic hatbakkers are not affected by the medial moraine hypothesis.

The medial moraine hypothesis may appear as in opposition to EHLERS (2011) that the hatbakkers are deposited on younger Baltic groundmoraine, and also to SMED (2014), who describes Langeland as an end moraine of the Baltic ice moving in from the east. Nevertheless, our interpretation of Langeland as a South-Norwegian medial moraine is justifiable, if the island has been compressed by Baltic ice, originating and modifying internal perturbations.

If the medial moraine hypothesis for Langeland is applicable, it would stand to reason that similar but much smaller structures on other Danish islands and in Jylland, as well as the material from eskers in southern Scandinavia have an analogous origin. The Langeland moraine most probably was only one of many medial moraines on the ice from Norway, whereas the Baltic glacier may have lacked medial moraines, as it was not surmounted by higher relief. Medial moraines, however, may have very different characteristics as shown by the figures in this paper. Their remaining deposits may exhibit small hills but also structures of long extension.

4 Discussion: Geomorphological importance of Ice Age medial moraines

The importance of medial moraines as landscape- forming elements so far has received little attention in treatments of the geomorphology of the Ice Ages. JOHNSON and MENZIES (in: MENZIES [ed.] 1996, 160) in the summary of their chapter "Pleistocene supraglacial and ice-marginal deposits and landforms" say: *"Supraglacial and ice-marginal deposits and landforms are among the more varied, complex, and distinctive [features] of the glacial system. Thus, Pleistocene supraglacial and ice-marginal deposits and landforms have and will continue to play an important role in both academic and applied aspects of glacial geo(morpho)logy."*

WAGNER and HANTKE since 1986 introduced the paradigm medial moraine into the discussion on alpine and pre-alpine Ice Age landscapes. They distinguished several types of landscape features of the Ice Age, based on medial moraine deposits:

1. *single forms*: singular or drop-like elongated accumulations formed by medial moraines ending at a glacier´s front.
2. *series*: successive lines of single structures from two or more successive equilibrium stages.
3. *longitudinal forms* in the extension of former glacier snouts.
4. *wide landscape-forming medial moraines:* broadly extended accumulations in front of wide medial morainic ridges or debris–covered glaciers. They may appear as drumlin fields or as hummocky moraines ("*Chaotic steep-sided piles of debris that lack a coherent directional pattern."* (MENZIES 1996, 133).
5. *Secondary border moraines*: Marginal ridges formed by accumulations of medial moraines, which turned into secondary lateral moraines.

In their publications from 1997 to 2014, HANTKE and WAGNER presented examples for these morphological types from the Alps and pre-alpine landscapes. Until then, most of these features were regarded as relict forms sculpted out of ground moraine by postglacial erosion, based on the tenet of PENCK and BRÜCKNER (1909). Their very high esteem of ground moraines probably was based on not appreciating that an advancing glacier with surficial debris always deposits it at its front because of continuous ice ablation while overriding the material at the same time. Thus, the original surface moraine becomes ground moraine. Note that PENCK and BRÜCKNER primarily worked on glaciers of the eastern Alps. Here, the mountains in the accumulation areas of the glaciers generally are of lower elevation compared to the central and western Alps, where the firn fields have been surmounted by the summits even during the largest Ice Ages by more than 1,000 m.

According to the "Medial-Moraine-Model", the above mentioned features generally are not formed from ground moraine debris but from surficial moraine material as ice-marginal landforms and possibly modified later by erosion. Small and tiniest landscape units belong to this category, but also important ones as the island of Reichenau in the Untersee of Lake Constance, the 35 km long and 100 m to 200 m thick morainic ridge below the postglacial sediments in Lac Leman (HANTKE 1980, 519), the largest moraines of Europe near Ivrea in northern Italy (WAGNER 2003, 379, 389) – and in our view the Danish isle of Langeland.

The counter-argument of an insufficient mass of medial moraines for the creation of such morphological structures (GRAF *et al.* 2003; BURRI 2014) can be easily refuted by a simple calculation. Based on a modest assumption of a mean debris thickness of only 10 cm, a glacier speed of 50 m/year and an equilibrium stage of 500 years (about the time of the Little Ice Age), at the end of the stadium, a cubature of 50 m of thickness and 50 m of length and the width of the medial moraine is accumulated, which is equivalent to the size of single structures discussed above.

5 Conclusions

The selected images of recent glaciers show that medial moraines during a longer time span with (small) glacier fluctuations may produce ice-marginal accumulations of geomorphological significance. Only the larger among such structures are visible in satellite images. Obviously, new fieldwork will find more examples.

In accordance with structures described firstly by WAGNER (1997, 2001) from Ice Age landscapes, the following forms and types of medial moraine accumulations are recognizable on the images:

- longitudinal even structures in the direction of the ice flow: Figs. 2, 5, 9, 12, 14, 16.
- structures with wedge-like widening to the end: Figs. 7, 8, 9, 10, 11, 17.
- longitudinal meandering structures: Figs. 3, 4, 14.
- wide structures of a hilly character (hummocky moraines): Figs. 3, 7, 10.
- series of similar structures in a row from different glacier equilibrium stages: Figs. 2, 6.
- short lateral accumulations from bordering and ending medial moraines: Fig. 2;
- long lateral ridges of secondary border moraines: Figs. 2, 5, 7, 14.
- a Y-shaped structure at the starting point of a medial moraine in particular is presented on Fig. 13, and at active glaciers on Figs. 2, 5, 14.

Even in the times of the most extended Ice Age glaciation, the alpine relief was never totally covered by ice, and, as a consequence, the valley glaciers received varying amounts of debris onto their surfaces. Based on the principle of actualism, it therefore is reasonable to accept that conditions for forming medial moraine landforms always existed. The same can be assumed on the aprons of Scandinavian glaciers during late-glacial phases of the last ice age. Thus, structures of these types in alpine valleys, the pre-alpine landscape of middle Europe, on aprons of late-glacial Scandinavian glaciers, as well as in homologous regions of other continents most likely derive from original medial moraines.

Thus, in consequence, a new paradigm is necessary for the landscape forming mechanisms in the region of alpine valley glaciers. Many landforms on the outer fringes of alpine and arctic glaciers, as well as elsewhere, which were difficult to explain or to understand or comprehend so far, now become plausible. These open questions will support new efforts to develop and to reach a consensus in glacial geomorphology. Additionally, the enigmatic drumlin-genesis may appear in a new light.

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