Jb. Geol. B.-A.	ISSN 0016-7800	Band 130	Heft 4	S. 383-389	Wien, Dezember 1987

On the Relationship of Bedrock Lithology and Grain Size Distribution of Till in Western Allgäu (West Germany) and Vorarlberg (Austria)

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With 6 Figures

Österreichische Karte 1 : 50.000
Blätter 82, 83, 111, 112, 113, 140, 141, 142, 143

Allgäu
Vorarlberg
Quarternary
Till
Sedimentology

Contents

Zusammenfassung

Korngrößen-Häufigkeitsverteilungen von über 200 subglazialen Moränen-Proben aus dem West-Allgäu und Vorarlberg mit Molasse und kontrastierendem Felsuntergrund im Intra-Alpinen Bereich zeigen, daß glaziale Aufnahme und Deposition von lokalem Material der wichtigste Faktor ist, der die Zusammensetzung der subglazialen Moräne bestimmt. In subglazialer Moräne, sedimentiert von lokalen Kar- und Talgletschern mit kurzen Transport-Distanzen und großen Gletschersystemen, mit potentiell langen Transport-Distanzen, werden übereinstimmmende Korngrößen-Verteilungen gefunden, hauptsächlich abhängig von der lokalen Lithologie des anstehenden Gesteins.

Abstract

The grain size distributions of over 200 subglacial till samples from Molasse (extra-alpine) and contrasting intra-alpine bedrock areas in western Allgäu and Vorarlberg, indicate that glacial uptake and deposition of local material is the most important factor determining the composition of subglacial till. In tills deposited by local cirque and valley glaciers, with short transport distances as well as large glacier systems, with potentially long transport distances, comparable grain size distribution characteristics are found depending mainly on the local bedrock lithology.

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1. Introduction

The grain size distribution in sediments totals the cumulative effect of many size distributions of individual rock types and mineral species and is therefore one of the most complex variables of a sediment. The determination of this property is probably one of the most frequently applied and standardized procedures in glacial sedimentology. However as a result of the complex genesis of grain size distributions, their characteristics can be interpreted in many different ways. This applies especially to subglacial till, where the specific mode of formation of the sediment as a whole is still far from being clear. In the present paper, we discuss some characteristics of size distributions in subglacial till from western Allgäu and Vorarlberg, that have been an important element in a recent controversy concerning the origin of glacial debris in till of this area.

DE JONG (1983) concludes that till deposited by the Rhine Valley glacier system in western Allgäu, consists primarily of far-travelled material. This is judged mainly on the basis of transparent heavy mineral and fine gravel composition. Also BIK (1960), studying tills of the Rhine Valley glacier in a part of western Vorarlberg observed that heavy minerals in till were mainly derived from non-local sources. In the same vein, DE JONG (1983: 62) suggests that several compositional aspects of till in the area can be explained by the concept of terminal mineral grades and the bimodal distribution of rock and mineral fragments as proposed by DREIMANIS & VAGNERS (1971, 1972).

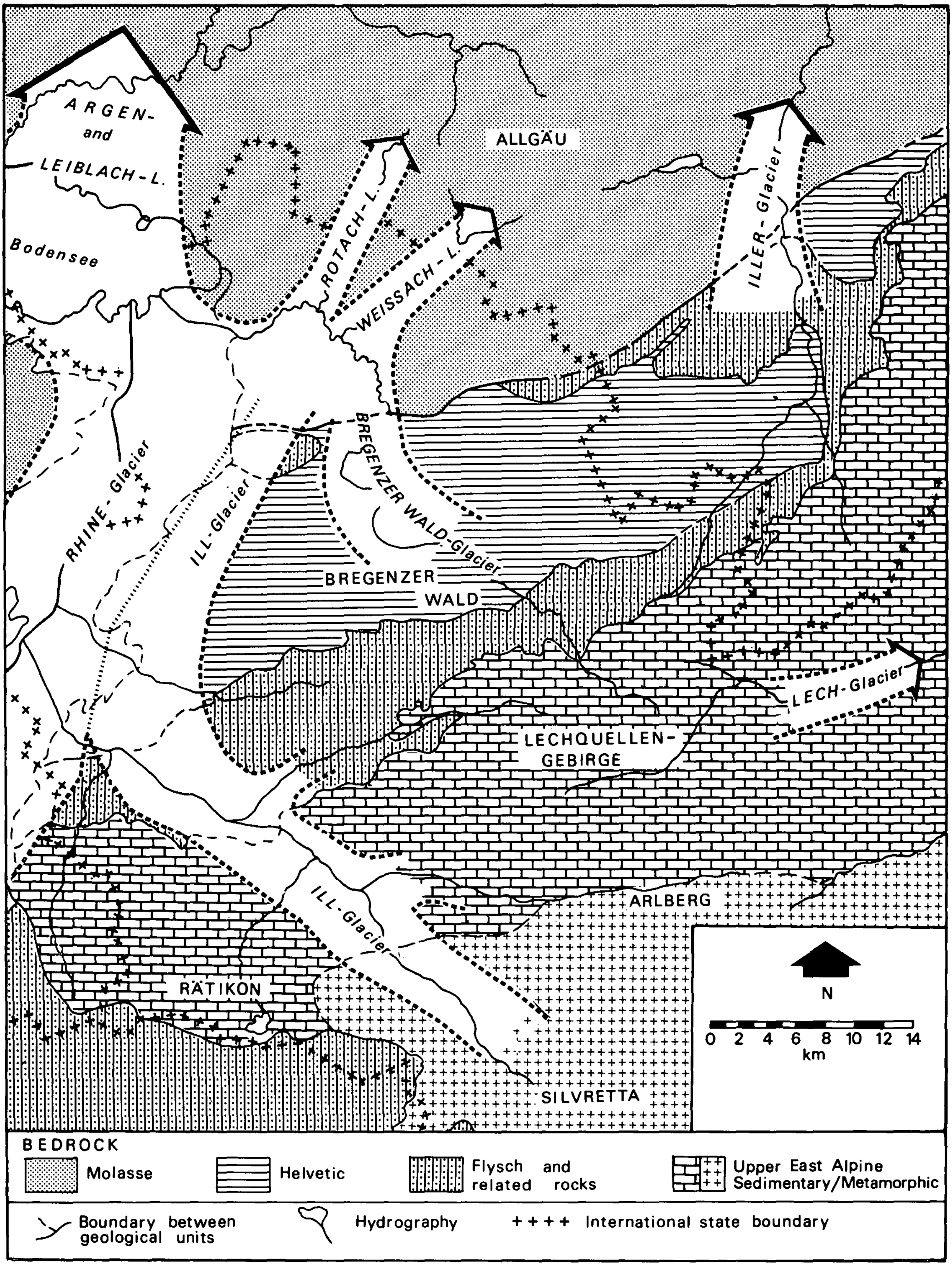

Fig. 1.
Simplified geological map of Vorarlberg and adjacent areas, with the approximate flow paths of the major (late Würmian) glaciers. Glacier extension in the source areas is not or only partly shown.
Geology after Geologische Karte der Schweiz 1 : 500.000, Schweizerische Geologische Kommission, 1972.

This view is opposed to the conclusion of GASSER & NABHOLZ (1969) and RAPPOL (1983), who interprete a strong and often dominant contribution of local bedrock lithologies and minerals to till in the Alpine Foreland. GASSER & NABHOLZ (1969) observe that in the Molasse zone of Switzerland variations in sand mineralogy of the Molasse bedrock are reflected in the overlying Quaternary deposits, and PETERS (1969) obtains similar results for the clay mineralogy. This view is supported by RAPPOL (1983), who indicates some of the characteristic features of the grain size distribution in till of the Molasse zone in western Allgäu to be inherited from the sedimentary rocks of the Molasse through crushing along grain boundaries, and therewith arrives at a similar model for the origin of the grain size frequency distribution in till as proposed by HALDORSEN (1981).

For subglacial till in the Traun Valley, VAN HUSEN (1981) found that after a short transport distance an "equilibrium size distribution" is established, showing no further general fining in a down-glacier direction (see also MILLS, 1977; BOULTON, 1978).

Our study area comprises source areas of several Würmian glacier systems as well as areas of maximal extension of some of these glacier systems in the Alpine Foreland. In fig. 1 the approximate flow path of the major glacier systems is indicated and superimposed on the geological zonation of the area.

The flow paths of the glaciers during their largest extension are strongly controlled by the large Rhine Valley glacier. The free outflow towards the west of the Bregenzer Wald and Ill glacier systems was obstructed by the Rhine Valley glacier. The Ill glacier was forced to flow to the north between Rhine glacier and the eastern Rhine Valley flank (e. g. KRASSER, 1936; SIMONS, 1985). East of the Bodensee, the Rhine Valley glacier diverged into several major distinct lobes, as a result of a number of bedrock-controlled valleys (Weissach- and Rotach-lobes, see Fig. 1). The Argen lobe area, north of the Bodensee, was controlled less by bedrock relief (see also KELLER & KRAYSS, 1980; DE JONG, 1983).

The geology is dominated by a zonation in several units, striking west-southwest to east-northeast. In the context of this paper a two-fold division is important into a Tertiary Molasse zone with well banked calcareous conglomerates, sandstones and shales versus lithologies of the Mesozoic flysch, Helvetic and Upper East Alpen nappes, being mainly clastic/hemipelagic, limestone/marl and limestone/dolostone bedrock, respectively. In the following, the latter are collectively referred to as "intra-alpine bedrock".

2. Method

Samples of about 2 kg were collected from subglacial tills exposed in pits and natural sections.

Over 200 till samples were collected from various parts of the area shown in fig. 1. The granulometric results used in this paper are taken from BIK (1960), CAMMERAAT (1986), DE JONG (1983), KWADIJK (1986) and RAPPOL (1983).

Moment measures (see e.g. FRIEDMAN & SANDERS, 1978) are calculated for the fraction smaller than 2 mm, with class intervals of 1 Φ and a clay fraction centered around 11,5 Φ). Sediment genesis was inferred in the field on the basis of structural characteristics and local sedimentological and geomorphological settings. Till-like resedimentation products (debris flows) may have been incorporated in a few cases, as these sediments are common in the Alpine glacial environments (e. g. VON KLEBELSBERG, 1948: 273; GERMAN et al., 1979; DE JONG & RAPPOL, 1983) and are sometimes difficult to differentiate from true tills in the case of poor exposure.

Gravel and sand fractions were determined by dry sieving at 1 Φ and 0,5 Φ intervals, respectively; clay and silt fractions were determined by pipette method at 1 Φ intervals. The fraction smaller than 2 mm ($-1\ \Phi$) was commonly pretreated with peroxide in order to remove possibly present organic compounds. The samples were not decalcified, the more so, because the content of primary carbonate rock fragments and minerals is very high (usually over 40 %, often more than 70 %). Consequently, artificial decalcification/dedolomitization would seriously disturb the glacigenic properties of the original grain size distribution. For example, destruction of the carbonate cement of the Molasse sandstone fragments would result in the creation of an artificial grain size distribution showing a mode in the 2–3 Φ fraction (RAPPOL, 1983: fig. 37). In the investigated area, cementation of till is seldom observed, except for the frequent occurrence of carbonate concretions in the thin strongly oxidized and weathered surface horizon and under very special hydrochemical conditions near gypsum outcorps (CAMMERAAT et al., 1987).

3. Results

The grain size distribution of samples belonging to the same glacial system are grouped together and a mean grain size distribution curve was constructed (fig. 2). Three groups originate from areas with "intra-alpine" substratum and four from the Molasse area.

At first, it appears that most curves are bimodal. One mode is present in the clast size fraction larger than $-1\ \Phi$ and a second mode is found in the silt size range. This typical bimodal distribution resembles similar types according to literature (DREIMANIS & VAGNERS, 1971; BOULTON, 1978 a. m. o.).

The basic difference between tills from the two areas lies in the distributions within the sand fraction. Whereas till on "intra-alpine" rock types shows a more or less evenly distributed frequency over the various sand-sized Φ-classes, tills in the Molasse area are characterized by a strong deficiency in the area of $-0{,}5\ \Phi$ and a consistent mode in the 2–3 Φ fraction. The latter would be much better expressed when we would plot the sand fraction at ½ Φ intervals and totalling 100 %, as shown in the example of fig. 3. A prominent mode is found at 2½–3 Φ and a second deficiency at 3–3½. The frequency distribution of carbonates was studied by BIK (1960) and RAPPOL (1983), indicating that carbonate content is highest in the coarse sand and silt sized fractions. As shown in fig. 3, the frequency curves of the calcareous and non-calcareous fractions are very similar, with a prominent mode in the 2–3 Φ fraction, and a deficiency around $-0{,}5\ \Phi$ in the area underlain by the Molasse bedrock. This similarity in size distribution of the calcareous fraction (mainly limestone and dolostone rock fragments) and the non-calcareous fraction (mainly quartz and feldspar) must clearly have re-

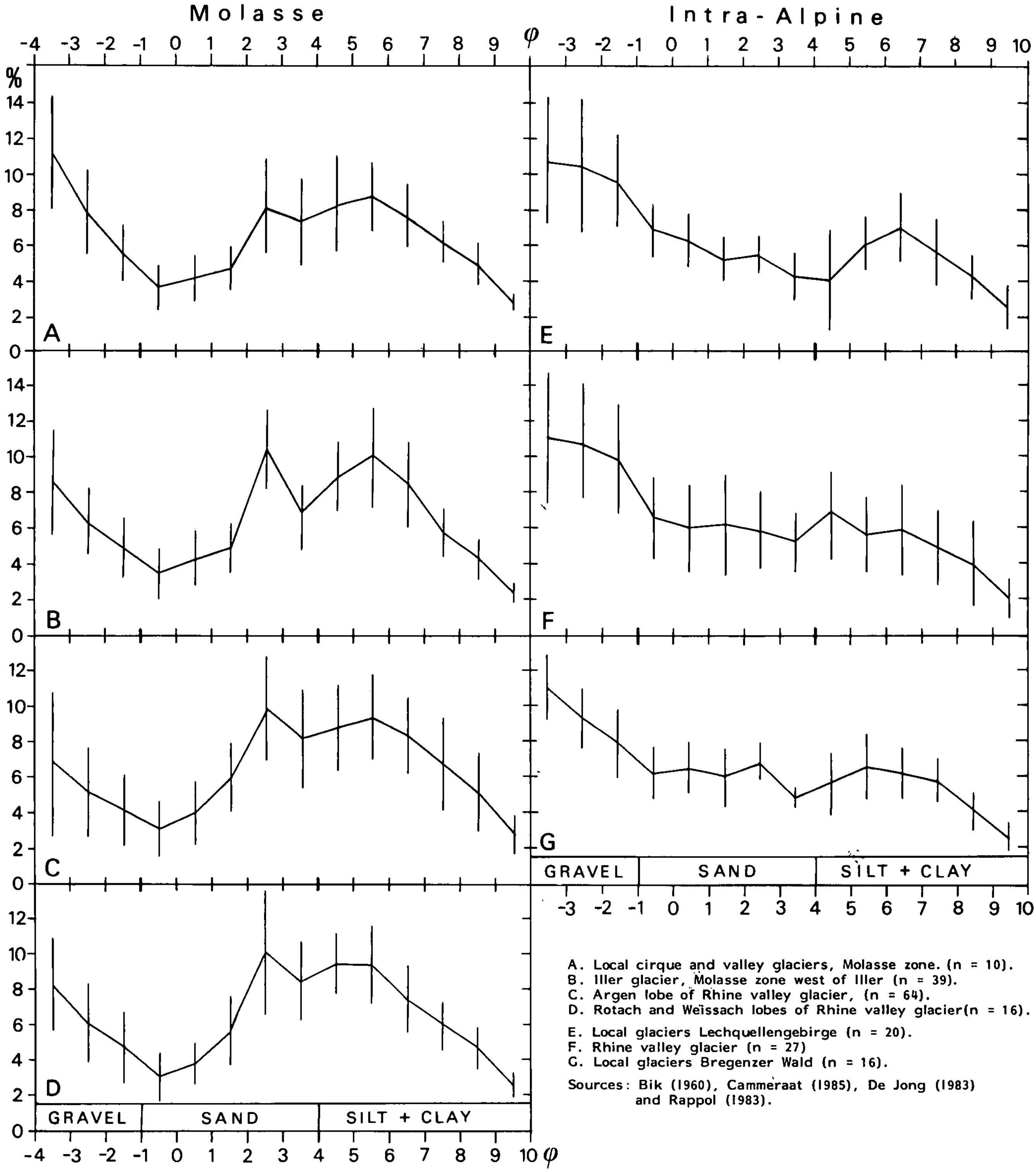

Fig. 2.
Mean frequency distributions of 7 groups of sampled tills: left side; Molasse Zone tills: right side; "intra-alpine bedrock" tills.
The vertical bars indicate standard deviation per Φ class.

percussions for the interpretation of the fragmentation history of these materials, as the results seem not in accordance with our expectations from the concept of glacial communition and terminal grades as proposed by Dreimanis & Vagners (1971).

Differences between both groups become more clear if we subtract the mean frequency distribution of the non-Molasse substratum areas from those of the Molasse areas as given in fig. 2. In fig. 4 four of such curves are depicted and all show common characteristics: a deficiency for the coarser fractions and a surplus for the silt-sized fractions of the samples of Molasse underlain areas in contrast with two "intra- alpine" samples.

If we plot skewness aganist mean size for each individual sample again a clear distinction is present between the "molasse" (open symbols) and "intra-alpine" (black symbols) groups of tills (fig. 5). It is shown that

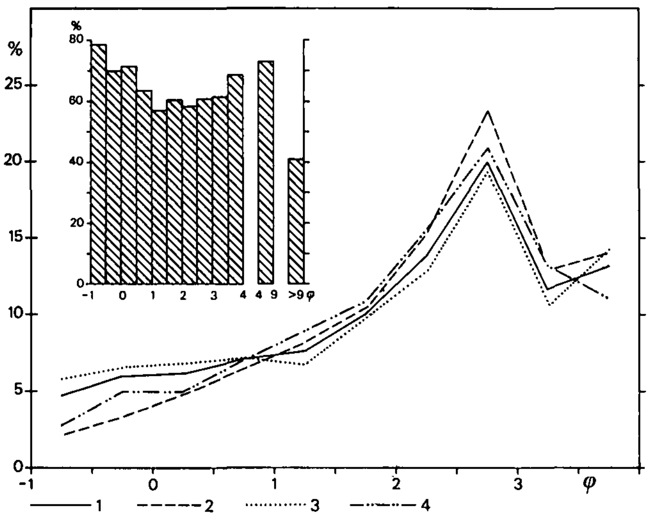

Fig. 3.
Frequency distributions per ½ Φ interval for the sand (is 100 %) of a till sample from the Molasse Zone (Alpsee Valley lobe of Iller Glacier).
The inset gives the percentage of of carbonate ($CaCO_3$-equivalents) in different fractions. The different curves represent frequency distributions of the
1) normally treated, calcareous sample split;
2) decalcified sample split;
3) carbonate fraction, as calculated from (1) and the fractionate carbonate content determinations;
4) non-carbonate fraction, calculated likewise..

for the same mean size value, till in the area of "intra alpine" substratum has a lower skewness value. As skewness is determined from Φ values, based on a negative log scale, positive skewness values mean a skewing to the finer fractions, which is in accordance with the results of fig. 4.

4. Discussion and Conclusions

The difference in grain size distributions of till in the Molasse zone versus that of the „Intra alpine" zone of Vorarlberg (fig. 4 and 5) cannot be due to a difference in transport length, because the same basic difference is observed when comparing tills deposited by local cirque and valley glaciers as well as by comparing tills deposited by larger glacier systems such as that of the Rhine Valley (see figs. 2 and 4). Consequently, the observed differences are interpreted as a clear expression of the different bedrock lithologies, and it follows from this that the till-forming debris is for a major part of local origin.

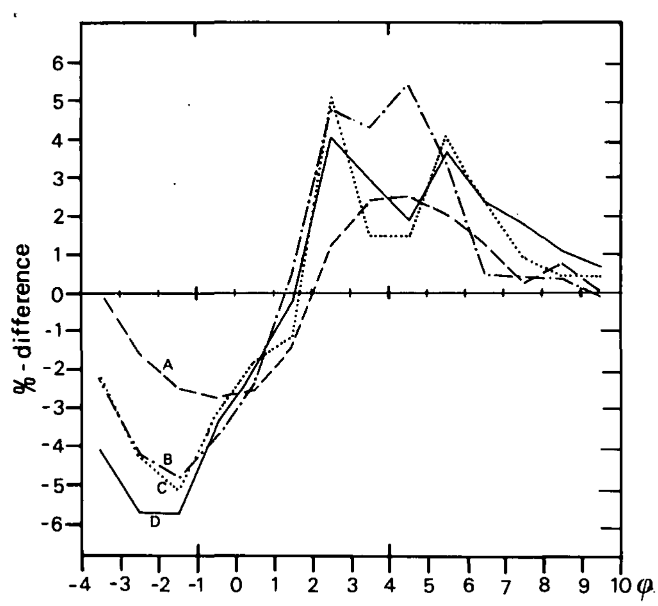

Fig. 4.
Examples of curves showing the result after subtracting mean "intra-alpine" frequency distribution curves from Molasse curves, as given in fig. 2.
A = curves 2A – 2G; B = curves 2D – 2E; C = curves 2B – 2F; D = curves 2C – 2F.

When BIK (1960) and DE JONG (1983) observe that the transparent heavy minerals in till of the Rhine Valley glacier are mainly far-travelled components, this is due to the fact that the heavy mineral concentration in the erratic debris is one or several orders of magnitude larger than in the local bedrock. As noted by BIK (1960), the calcareous rocks of Vorarlberg contain no or very few heavy minerals and also in the Molasse rocks, heavy mineral weight percentage seldom rise above 0,5 % (HOFMANN, 1957; FÜCHTBAUER, 1964). Weight percentages can be estimated (conservatively) to be in the order of 2–6 % for the erratic component as far as this contains material derived from igneous and metamorphic sources. Likewise, in modern river sediments of the area, the heavy mineral composition is dominated by those originating from areas where crystalline rocks crop out, such as the Silvretta and Rheinwald areas (HAHN, 1969). Moreover, especially in the case of the Argen-lobe area studied by DE JONG (1983), far-travelled components may have been reworked to a large extent from sub-till glaciofluvial deposits.

The composition of the transparent heavy mineral fraction is thus a very poor measure for estimating the relative contribution of erratic and local components, because addition of the latter will hardly change the compositon of the heavy minerals, but only lower their concentrations. Only where there is no large difference in the heavy mineral weight percentages between the local and erratic components, we expect a strong relation between the heavy mineral composition of the bedrock and till as observed by GASSER & NABHOLZ (1969). DE JONG (1983) pointed out that such a relationship does not exist in a large part of the area covered by the Rhine valley glacier. On the other hand, recent investigations in the Rotach Valley support the findings by GASSER & NABHOLZ (1969). Here an epidote-rich zone in the Molasse has a pronounced effect on the heavy mineral composition of till immediately down-ice of its outcrop zone (fig. 6). Similar results were obtained in the Upper Lech Valley where augite minerals are common in tills (partly) derived from local volcanite interlayerings in the Arlberg Formation (CAMMERAAT, 1986). In these latter cases, the contribution of material from igneous and metamorphic sources however is low or very low. When a variety of compositional parameters is considered, there can be no doubt that most till-forming debris underwent only a short transport distance. The exception that supports the rule is represented by till overlying glaciofluvial deposits that are rich in far-travelled components. Usually, in such a case at least the lower part of the till contains much far-travelled material, also.

The main features of the grain size distribution in the study area can therefore not be interpreted in terms of the "terminal mineral grade" concept of DREIMANIS & VAGNERS (1971). However, by no means does this imply that the basic assumptions of this concept are in-

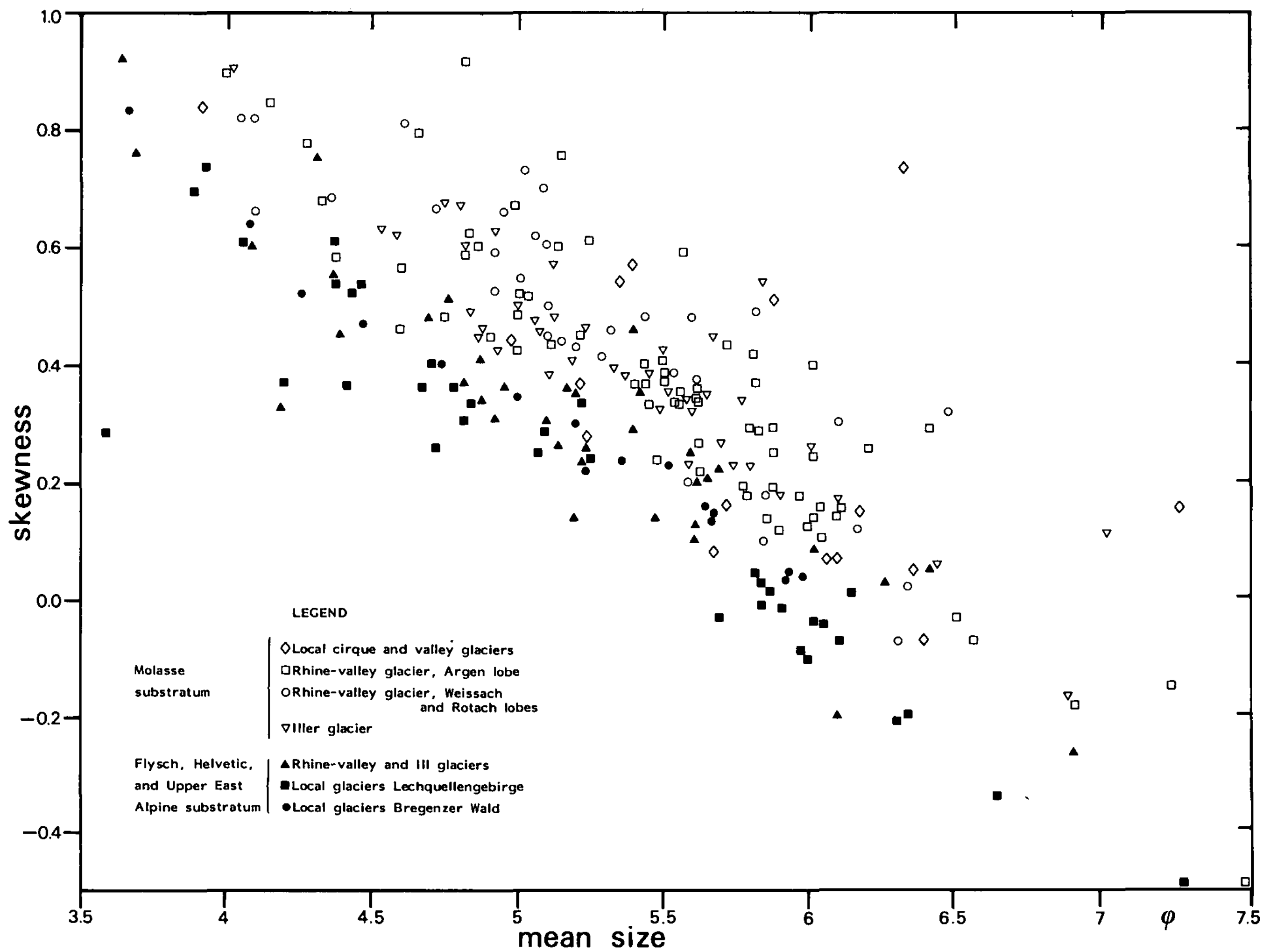

Fig. 5.
Graph with mean size plotted versus skewness for all samples.
Molasse till samples: n = 134; Pearson corr. coeff.: r = −0.87; Sk = −0.40x + 2.56.
„Intra-alpine" till samples: n = 88; r = −0.86; Sk = −0.37x + 2.17.

correct. In fact, the concept could be very well tested in the area by a study of the amphibole minerals and their main source, the amphibolite rocks, as in the Alpine Foreland amphiboles are virtually absent in local rocks.

Frequency distributions based on the logarithmic Φ-scale usually show a number of modes and "gaps" that are frequently recurring in sediments of different genesis and in areas of very different bedrock terrains. WENTWORTH proposed that there are two strong gaps in grain size distributions, one at −1 Φ and one at 8 Φ, with a weaker gap at 3,5 Φ (according to FOLK, 1966: 81). In till we frequently observe that all materials occurring along an ice-flow line are found thoroughly mixed, and in general we may therefore expect for till modal fractions in the clay, coarser silt, medium sand, and coarser gravel fractions. The grain-size distribution within the clay fraction, spanning an infinite number of Φ-classes, is seldom analysed. The mode in the gravel fraction is found all over the investigated area, and in fact is present in most till produced dominantly from hardrock sources (e. g. BOULTON, 1978; DREIMANIS & VAGNERS, 1972). The precise location of this mode is probably determined by the spacing of joints and other planes of weakness in the source rocks; or, in the case of conglomerates with a relatively weak cement as in the molasse, by the dominant clast-size in the conglomerates. A weak to strong modal fraction of 2–3 Φ as

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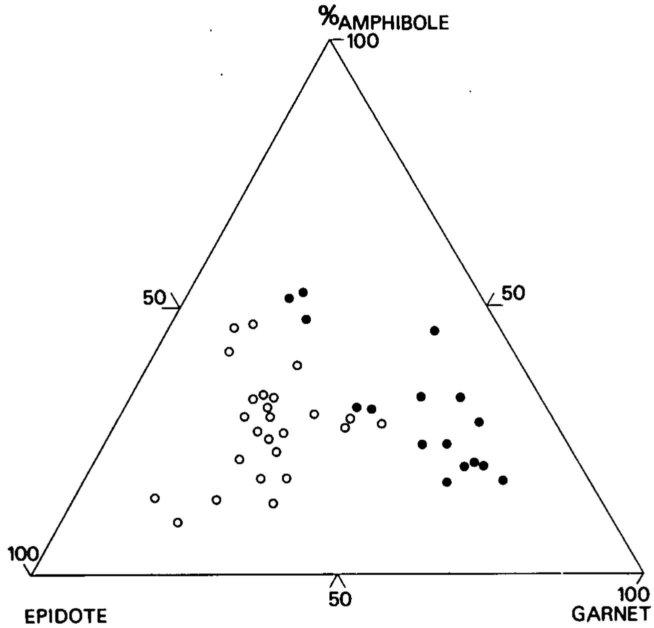

Fig. 6.
Heavy mineral composition of till in the Rotach Valley. Down-ice of the epidote-bearing zone in the Upper Marine Molasse, many till samples contain anomalous amounts of epidote (open circles), while up-glacier of this zone, till shows a normal variation in the relative frequencies of amphibole, garnet and epidote (●). This diagramm demonstrates the strong influence of local bedrock on till where the heavy mineral content of the erratic debris is relatively small.

hardrock sources (e. g. BOULTON, 1978; DREIMANIS & VAGNERS, 1972). The precise location of this mode is probably determined by the spacing of joints and other planes of weakness in the source rocks; or, in the case of conglomerates with a relatively weak cement as in the molasse, by the dominant clast-size in the conglomerates. A weak to strong modal fraction of 2–3 Φ as usually found in the Molasse area, is reported from many areas with a variety of source rock types, such as sandstones, metasandstones and unconsolidated sand (e. g. HALDORSEN, 1981; RAPPOL, 1987) and igneous rocks (e. g. DREIMANIS & VAGNERS, 1971; VORREN, 1977). This mode is frequently attributed to the location of many terminal grades in this fraction, among which that of important minerals as quartz and feldspar (DREIMANIS & VAGNERS, 1972; VORREN, 1977; DE JONG, 1983). On the other hand, HALDORSEN (1981) showed that in her samples, the 2–3 Φ mode was inherited from the sandstone bedrock by crushing along grain boundaries. For till of the "Molasse zone", RAPPOL (1983) suggested a similar origin of this mode, primarily based on the fact that this mode is also present in the carbonate fraction (mainly rock fragments), suggesting that the materials must have inherited sorting from the source rock (Molasse sandstone).

A broad mode in the silt fraction present in till in most of the investigated area may be explained likewise, as being the result of crushing of calcareous shales that are abundantly present in the bedrock in most areas.

Acknowledgements

We thank Dr. Sylvi HALDORSEN and Dr. Jan RUPKE for their critical remarks and suggestions, which substantially improved the content of this paper.

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