APPENDIX IV

PETROGRAPHY AND POSSIBLE ORIGIN OF ADZES AND OTHER ARTEFACTS FROM PREHISTORIC SITES NEAR HIENHEIM (BAVARIA, GERMANY) AND ELSLOO, SITTARD AND STEIN (SOUTHERN LIMBURG, THE NETHERLANDS)

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INTRODUCTION

The main objective of the present study is to correlate prehistoric artefacts with a possible geological source. Petrologically artefacts are rock fragments and before discussing their origin, two important aspects should be mentioned. Firstly the term "source" or "origin" may be interpreted differently by geologists and by prehistorians. Secondly the prehistoric artefacts investigated are in fact always selected samples.

What may have happened to rock material of archeological importance between its geological formation and the moment that certain parts are found as artefacts?

Prehistoric artefacts are generally made of carefully selected rock types, which are exceptional varieties of igneous, metamorphic or sedimentary rocks. The commonly selected rock types may have been quarried at the sites where they were originally formed by the rock-forming processes in the earth's crust (referred to as geologically primary sources; fig. 37) or may have been found as boulders or pebbles transported by exogenous geological processes, such as flowing water or ice, (far) away from the original place of formation. These rock fragments (boulders, cobbles, pebbles) in sediments (referred to as secondary sources) offered prehistoric man a natural choice of hard and tough materials that appeared to be very resistant to weathering and wearing by erosion and transport.

With the exception of the finds in prehistoric quarries the selected samples may have been transported by man ("trade") over considerable distances. It is also possible that the material passed through more than one prehistoric site before it reached its ultimate owner, i.e. the place where it was ultimately found. From the above it is obvious that the "source" of the investigated artefacts is often highly speculative.

Most artefacts from the sites investigated are made of chert, quartzitic rock, basalt and amphibolite. Chert, quartzite and quartz arenite or "sandstone" occur in almost all European countries as primary and/or as constituents in secondary deposits (sedimentary deposits). Primary basaltic and especially amphibolitic rocks occur geologically in more restricted areas (see later). The rock components of sedimentary deposits were transported by glacial ice (Pleistocene) and/or rivers in different directions. Glacial deposits in the northern part of Central Europe are northern in origin (Scandinavia; enclosures 6 and 7) and include all the above-mentioned rock types.

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	origin of the rock	*aspect of the rock*	*processes*
A	geologically primary source: crystalline basement	more or less fresh outcrops	rock forming processes in the earth's crust
B	geologically secondary source: sedimentary deposits	selected boulders, cobbles, pebbles	selection by geological process, i.e. weathering, erosion, transport
	(human interference)		
AX/BX	sampling site or quarry	i.e. rock fragments	human selection
			human transportation (further selection)
Y	workshop	waste, rough-outs, implements	
			human transportation (further selection)
Z_1	place of use (e.g. settlements)	implements, reworked implements, waste	
			human transportation (further selection)
Z_2	second place of use	implements, reworked implements, waste	
	etc.	etc.	

Fig. 37. Complications in the search for "the source" of prehistoric artefacts.

It appears, however, that the artefacts found in the prehistoric sites mentioned in this article are Central European in origin as will be discussed in later paragraphs.

AVAILABLE PREHISTORIC ARTEFACTS

HIENHEIM

All the adzes, adze fragments, rough-outs and waste material excavated at the Hienheim prehistoric site and classified as belonging to the Linearbandkeramik culture (LBK) were made from amphibolitic rocks. Adzes of basaltic rock or black siliceous shaly rock were not encountered, although some of the known outcrops of basaltic rock lie only 115 km NNE of Hienheim (encl. 7; Strunz 1975). The quern fragments consist of unmetamorphosed quartz arenites and quartzite.

ELSLOO, SITTARD AND STEIN

In contrast to the Hienheim prehistoric site, the implements found at the LBK sites in the southeastern part of the Netherlands were made not only from amphibolitic rock but also from basaltic and siliciclastic rocks, i.e. (meta)quartzites and black siliceous shales including lydite.

Fragments of querns and grinding-stones consist of unmetamorphosed quartz arenites and quartzites.

PETROLOGICAL INVESTIGATIONS

The available prehistoric artefacts were investigated with the aid of a low-magnifying binocular microscope; only a few thin sections were cut for further analysis.

When possible the thin sections from amphibolites were made by cutting the rock fragments perpendicular or oblique to the foliation plane (lineation), an important prerequisite when such rocks are compared in any detail.

All the relevant information concerning the amphibolitic and basaltic artefacts was grouped according to the properties of the constituent minerals, the rock structures and other properties; see tables 22 and 23 (enclosures 8 and 9). A selection of photo(micro)graphs of surface textures and internal features have been added as important sources of information for correlation.

To obtain conclusive evidence of the correlations, more extensive methods (mainly geochemical) seem inevitable for future investigations. Trace element analysis and pattern recognition (de Bruin et al. 1972) might possibly be applied successfully for correlation of basaltic and amphibolitic material. A serious objection to most investigations is that the methods are generally destructive, although it is always possible to limit the "damage".

Finally it must be emphasized that a broad reference collection of archeologically "proper" source rocks is of primary importance for any effective correlation.

The investigations carried out for this study included only the more conventional methods; moreover the relevant proper reference collections are still small. The conclusions made here must to a certain extent be regarded as preliminary.

AMPHIBOLITES FROM CENTRAL EUROPEAN SOURCES

Amphibolites are dark-coloured metamorphic rocks generally displaying a schistose structure, i.e. parallel orientation of the dark minerals (amphiboles, biotites).

Calcareous sediments and basic rocks of plutonic origin, like gabbros, or of volcanic origin, like basic tuffs, basalts, etc. and basic dikes or dolerites, may change progressively (metamorphism) into amphibolites due to increasing pressure and temperature. It is also possible that the amphibolites are the result of a retrogressive metamorphism of rocks of a higher metamorphic grade (granulites, eclogites). Metamorphic processes occur on a regional scale in crustal areas of mountain-building. The ultimate metamorphic product may be isochemical with respect to the parent rocks, but it is also possible that the chemical composition has changed (metasomatism). It should be stressed that the above-mentioned genetic aspects of the metamorphic rocks, e.g. amphibolites, play an important role in the evaluation of the geological source and history of the material investigated.

As amphibolites may occur in all metamorphic terrains, the level of crustal erosion will determine whether amphibolites are encountered or not. Both the Alps and the Carpathians are part of a geologically young mountain range (Alpine Orogen); the originally deeper parts now cropping out on the Earth's surface often contain amphibolitic rock. But nearer to the prehistoric sites of the present study the remnants of an older mountain range crop out, i.e. the Variscan or Hercynian Orogen of Central Europe (encl. 6). Amphibolites from the Variscan have also been found in many localities and, as can be seen from the map, they occur most frequently in the southeast and are absent in the northwest.

THE VARISCAN OROGEN IN CENTRAL EUROPE

This old mountain range can be divided geotectonically into several zones (Lotze 1971); parts of these zones crop out and are known to us under regional names. They are indicated on the map (encl. 6).

To the northwest the Rhenohercynian Zone includes the Ardennes-Rhine Massif, the Hunsrück-Taunus Massif and the Harz. Deformation structures trend NE-SW and only the southeastern rims of the Hunsrück, Taunus and Harz display a low-grade metamorphism.

Adjacent to the former zone is the Saxothüringen zone which contains crystalline basement rocks of low to medium-grade metamorphism with NE-SW structures. The Vosges, Black Forest, Odenwald, Spessart and the northwestern part of the Bohemian Massif belong to this zone while the Sudeten Range and Silesicum can be explained as a NW-SE trending continuation (Vejnar 1971). The Münchberger Mass and the Granulitgebirge are basement cores of a higher metamorphic grade. Farther to the southeast the Moldanubian Zone, structurally heterogeneous, consists of basement units with different orogenic and metamorphic histories. To the west the Oberpfalz Forest, Bavarian Forest and Bohemian Forest have NW-SE structures and show a medium to high-grade metamorphism.

From the above it is apparent that the deepest parts of the Variscan are exposed in the southeastern part of the range. Age determinations and structural-petrological data indicate that parts of the basement are polymetamorphic, i.e. underwent earlier (Pre-Variscan) phases of deformation and metamorphism (Vejnar 1971; Stettner 1975).

BASALTIC ROCKS IN CENTRAL EUROPE

The volcanic rocks of Central Europe, which grade from acid to (ultra) basic types, were extruded roughly during two main periods of volcanic activity.

The older volcanic activity was connected with the Variscan Orogeny. It started with initial magmatism (basic rocks) in zones of geosynclinal sedimentation lasting from the Lower Devonian to the Lower Carboniferous – e.g. in Sauerland, Harz, Schiefergebirge, Vosges, Thüringen, etc. – and continued mainly in the Permian with magmatism as a result of block movement in the already rigid Variscan Orogen (Knetsch 1963); locally this caused large-scale extrusions of quartz porphyries, basalts, etc., e.g. in the Saar-Nahe area.

The younger period of volcanic activity, lasting from the Upper Cretaceous to the Quaternary, is again closely connected with large-scale crustal dislocations in a zone west and north of the Alpine Orogen. The centres of volcanism were restricted mainly to areas near or within graben(-like) structures, e.g. the French Central Massif, the Rhine Graben and Hessian Depression, and the Northwestern Bohemian Massif (encl. 7). These volcanic rocks can be found not only as extrusions near the graben but also at the junctions of cross-cutting fault systems. The main Central European Tertiary volcanic districts are the Hocheifel - Nordeifel - Siebengebirge area, Vogelsberg, Westerwald, Rhön - Lower Hessen area, Kaiserstuhl, Doupovké Horý, České Středohoři and the Lausitz-Silesian area. Volcanism in the Laacher See area and the Western Eifel is of Quaternary origin.

Petrologically the European neovolcanic rocks are alkaline rocks whereby alkali olivine basalts form the major rock type. They occur in specific associations, e.g. olivine basalt – tephrite – phonolite, which are representative of relatively stable crustal areas with major faulting (Wimmenauer 1972, 1974). Many basalts were intruded (sub-volcanic) as dikes and dike swarms, while basaltic volcanic plugs as well as basaltic lavas and tuffs also occur.

HIENHEIM

AMPHIBOLITIC MATERIAL

A total of sixty-six amphibolite samples, sixty of which were classified as LBK, was available for examination. Thin sections were made from twenty fragments.

Description of the samples

On the basis of grain size, structure, polish and colour of the patina,[1] this population has been tentatively subdivided into two main groups of 21 (including 7 thin sections) and 45 (including 13 thin sections) specimens, respectively.

Macroscopically the members of the first group are very fine grained with thin and often irregular layering. Leucocratic more coarser grained layers and cross-cutting veinlets are common. Due to these properties the artefacts display a fine polish and a splintery fracture (fig. 38). On the basis of the colour of the patina a further subdivision was made. The implements vary from light brownish green (Ia) and brownish green (Ib) to dark grey (Ic).

[1] The use of surface polish and patina colour for the classification of artefacts is hazardous due to differences in weathering conditions at different places and levels of the site.

Group Hienheim I consists of the following samples:

I a: 1140–2, 1140–3, 511, 344 t.s.[1], 550, 183–1 t.s., 359* t.s. and 728

I b: 1063–1, 699 t.s., 183–3, 183–2 and 265,
721–1, 764–1 t.s. and 530* t.s.

I c: 726–1 and 1089,
349, 380 and 266 t.s.

A subdivision of the implements of the second group was based upon the grain size. They vary from very fine grained (IIa), a slightly coarser grain (IIb) to more coarser grained (IIc). The individual differences in grain size of the mineral constituents may be pronounced, especially within the more coarser grained samples. Individual minerals and mineral clusters may be visible with the naked eye (fig. 38). The implements of the second group also vary in colour from light green and brownish green to dark green. The surface polish is not as smooth as that seen in the first group.

Group Hienheim II consists of the following samples:

II a: 307–1, 545, 1083 t.s., 182–2 t.s., 715*, 737, 607, 720, 602, 292–1 t.s., 1063–3 and 593

II b: 206* t.s., 526, 182–1, 729, 726–2, 929 t.s., 1062 t.s., 1063–2 t.s., 271, 764–2, 292–2, 489, 401, 617 and 1082–2

II c: 307–3, 477, 412, 721–2 t.s., 476, 685* t.s., 701, 703,
1140–1 t.s., 1082–1 t.s., 12, 325 and 307–2

II d: 718* t.s., 919 t.s., 748, 343 and 921

The samples of subgroup IId are rather irregular with respect to grain size, structure and colour. Sample 748 is a rough-out that contains relatively large porphyroblastic hornblende clusters and brown hornblende is the main constituent of adze 343.

Thin section analysis

The mineral composition and other petrographic properties of the amphibolites are listed in table 22 (enclosure 8). A sharp demarcation between the two implement groups with respect to mineral composition and properties is not present, although each group displays certain characteristics.

The most important constituent in all the amphibolites is an almost colourless to light bluish-green *hornblende*. The almost colourless (*actinolitic*) hornblende is especially abundant in the amphibolites of the first group, while bluish-green hornblende is more abundant in the second group, especially in the more coarsely grained varieties. The textural pattern of the hornblende is highly characteristic. It may occur firstly as individual needles or sheafs oriented parallel to the foliation or (more often) at random, secondly as microcrystalline crystal aggregates with bushy outlines (fig. 42), and thirdly as an irregularly shaped coarser variety (fig. 43).

Amphibolites rich in radial or sheaf-like hornblende clusters (fig. 44) are known in German literature as "Strahlsteinschiefer" (Bauberger et al. 1973). The larger crystals or sheafs are particularly well-developed when they occur together with recrystallized quartz and albite (fig. 45). Sometimes relatively larger hornblende porphyroblasts have developed (fig. 46).

[1] t.s. = thin section

* not LBK

The larger hornblende grains display a deeper blue-green colour. In a few cases traces of an older brownish hornblende are visible.

After hornblende the main constituents are ore minerals, quartz and/or plagioclase (albite). A typical aspect of almost all the amphibolitic implements is the presence of numerous *ore mineral* grains or clusters. Ore minerals in Central European amphibolites were identified by Scholz (1968) as mainly ilmenite, with some magnetite and pyrite, and by Štelcl et al. (1970) as arsenopyrite. *Quartz* is either fine grained or recrystallized. A polygonal or mosaic fabric of recrystallized quartz in layers or lenses is often characteristic.

Plagioclase (albite), seldom twinned, may also occur as small grains throughout the rock or concentrated with quartz in layers and lenses. An initial porphyroblastic recrystallization may be observed.

Epidote is generally present in variable amounts but seems more frequent in the first group. In addition to saussuritic masses relatively large crystals occur. Other constituents are *biotite*, *chlorite*, *muscovite* and *titanite*, the latter sometimes as numerous small rounded grains concentrated in quartz and feldspar.

In thin sections layering or foliation is generally clearly visible and sometimes pronounced (fig. 47). The layering of some of the implements of the first group may reflect an original depositional layering (tuffs). Strings of ore minerals are oriented parallel to the layering. Small-scale faults with crenulation effects acted upon some of the amphibolites, before as well as after metamorphism.

Possible provenance of the amphibolites

Most of the amphibolites from Hienheim are characterized by the low-grade metamorphic mineral assemblage actinolitic hornblende ± biotite ± chlorite ± epidote ± plagioclase (albite) ± quartz (greenschist facies). Relics of a higher grade of metamorphism have not been encountered.

The coarse-grained varieties have reached higher stages of low-grade metamorphism with larger amphiboles (porphyroblasts) and a deeper blue-green colour.

The sheaf or garven-like pattern of the amphibole needles, which is the cause of the toughness of the "Strahlsteinschiefer" amphibolites, indicates that the originally mafic rocks crystallized under relatively low pressure and high temperature metamorphic conditions. Stress-fabrics were rarely encountered and after metamorphism no penetrative deformation affected the amphibolites.

The presence of a well-developed thin "sedimentary" layering, sometimes weakly folded, in combination with a large quantity of ore minerals might indicate that these rocks were originally mafic volcanic rocks (Bauberger et al. 1973).

Three geological possibilities may be mentioned with regard to the source of the amphibolitic artefacts: firstly the quaternary glacial deposits derived mainly from Scandinavian (primary) sources, secondly the Alpine Orogen (Alps and Carpathians; Štelcl et al. 1970) and thirdly the Variscan basement of Central Europe.

Hermann & Schüller (1951) in a study of artefacts from Southern Saxonian prehistoric sites found that only in exceptional cases were implements made from northern erratics. No artefacts of amphibolitic composition were described and according to Scholz (1968) this rock type is a rare constituent of the glaciogenic deposits.

On the basis of the geological and (scarce) petro-archeological literature it is most likely that the source of most of the amphibolitic artefacts from Central European prehistoric sites is Variscan. The same applies for Hienheim, and a choice of sources seems to be nearby.

In the first place the western margin of the Moldanubian zone should be considered. Here medium to high-grade polymetamorphic rocks crop out that underwent Late-Precambrian to Variscan phases of deformation and metamorphism. Rather small amphibolites and other metabasites (serpentinites, marbles, lime-silicate rocks) occur scattered throughout the Bavarian and Regensburger Forst (Troll & Bauberger 1968; Troll 1975; Stettner 1975). The main mafic constituent of the amphibolites is often brown hornblende, e.g. Steinbügel near Wörth 50 km ENE of Hienheim. The majority of the amphibolites, however, are metagabbros. All the amphibolites contain blue-green hornblende as a rim around brown hornblende and/or pyroxene or replacing these minerals completely. In some metagabbros a blue-green hornblende rim encloses a lighter blue-green or colourless hornblende, both secondary to pyroxene. The blue-green hornblendes are Variscan and the corresponding metamorphism has been described as a low-pressure and high- temperature ("Abukuma") type of metamorphism (Vejnar 1971). The presence of brown hornblende, however, might possibly be connected with progressively higher grade elements of the same facies series (Schreyer & Blümel 1974).

Twenty-one amphibolite outcrops were sampled in the Western Moldanubicum but no amphibolitic rocks similar to the majority of the Hienheim artefacts were encountered. Only in one case does a Western Moldanubian provenance seem evident, that is the brown hornblende-bearing amphibolite 343.

Metagabbros which crop out near the prehistoric sites of Knöbling and Thierling (Regensburger Forest) are weakly amphibolitized. In rock fractures in particular blue-green hornblende is present, sometimes as rosettes (fig. 48). Bauberger et al. 1973, who investigated similar rocks in that area, suggested that more markedly deformed parts of the metagabbro might have been the source of some of the implements excavated nearby.

East of the Oberpfalz, and continuing into Czechoslovakia, a large partly amphibolitized gabbroic intrusion crops out (Schreyer & Blümel 1974) and within the Oberpfalz farther to the northwest, the more common amphibolites and serpentinites occur together with eclogite-amphibolites and garnet amphibolites indicating high-grade metamorphic conditions (high-pressure "Barrovian" type) prior to Variscan metamorphism (Stettner 1975). Serpentinites and amphibolites are often closely related (Klinkhammer & Rost 1975).

Contact metamorphism in the serpentinites due to Variscan intrusion of granite resulted in the growth of amphibole rosettes and occasionally narrow (20–30 cm) tremolite "Strahlstein" layers.

The northwestern to northern peripheral zone of the Bohemian Massif, i.e. the Saxothüringicum, consisting of Precambrian and Lower Palaeozoic rocks, is a second, possibly more promising area to be considered as the provenance of the artefacts. The rocks in this area are generally characterized by a low-grade (epizonal) metamorphism, in which progressive and retrogressive metamorphism is evident (Mielke & Schreyer 1969; Stettner 1974). Geotectonically aberrant complexes are the Münchberger Mass ca. 150 km north of Hienheim, and the Granulitgebirge farther to the northeast. They contain high-grade metamorphic rocks such as eclogites and granulites. Among the mafic Palaeozoic rocks of the Münchberger Mass lower-grade epidote-albite amphibolites and chlorite amphibolites occur.

Locally the Late-Precambrian basement rocks of the Fichtelgebirge include mafic (sub)volcanic rocks. Their mineral assemblage is characterized by chlorite + actinolite + epidote + albite + biotite. In places a subsequent contact metamorphism, due to the intrusion of Variscan granites, affected the basement rocks. A sheaf-like recrystallization of hornblende or the growth of large porphyroblasts has been observed in some amphibolites (Dimroth 1960).

Amphibolites have also been reported from the Thüringen Forest and Thüringen Schiefergebirge, the Erzgebirge and the Sächsische Zwischengebirge (Pietzsch 1962). Recently Scholz suggested sources in

Thüringen and Münchberg for some of the Hienheim implements (Scholz, written comm.). With respect to the amphibolitic artefacts found in Southern Saxonian prehistoric sites, Herrmann & Schüller (1951) favour the nearby Frankenberg-Hainichener Zwischengebirge (250 km NNE of Hienheim) as the source area. In this area amphibole-epidote schists (greenschist facies) occur which are regarded as retrogressive products due to strong mylonitization. These rocks, also called prasinites, are fine grained and either massive or schistose.

The metamorphic mineral assemblage comprises hornblende, chlorite, epidote, albite, quartz, titanite and calcite.

Along the northeastern margin of the Bohemian Massif (Sudetic zone) a few amphibolite-bearing areas have been indicated as potential provenances of artefacts. In a study of Neolithic amphibolitic implements found in Central Czechoslovakia, Štelcl et al. (1970) have suggested the Rychlebské Hills and Hrubý Jesenik Mountains as possible source areas. Frechen has often referred to the Sobótka (Zobten) area in Southwestern Poland as the provenance of amphibolitic artefacts (Frechen 1965; Frechen, written comm.). A series of reference samples from Mount Kósciusko (Zobten area), which was kindly placed at our disposal by Dr. A. Majerowicz, was investigated. These rocks are amphibolites with varying grain sizes; deep blue-green hornblende pophyroblasts forming well-crystallized sheafs (fig. 49), porphyroblastic plagioclase and dispersed ore minerals are the main constituents with some biotite and very little secondary epidote, chlorite and titanite. In spite of the sheaf-like pattern of the hornblende, these rocks do not resemble the typical Strahlsteinschiefer amphibolites.

Five thin sections made from amphibolites belonging to the University of Bonn could be examined through the kindness of Prof. Dr. J. Frechen. The geological source was identified as the Zobten area although the exact localities are unknown. Two samples were typical finely banded Strahlsteinschiefer amphibolites and one a nephritic rock (no. 220); the other two were metagabbros (no 215). The amphibolites from the Sobótka (Zobten) area are partly surrounded by gabbros and serpentinites which contain a few small nephrite outcrops (Geschwendt 1976). These nephrite deposits may possibly have a Variscan origin similar to that of the tremolite bands in the Oberpfalz serpentinites (Klinkhammer & Rost 1975). Nephrite has also been found in serpentinites close to the Czechoslovakian border (Rychlebské Hory or Reichensteiner Hills).

Though not enough reference material is available to establish the source of the Hienheim artefacts, one is inclined to conclude that the Fichtelgebirge, Thüringen and the Frankenwalder Zwischengebirge are the most probable areas of provenance and possibly but less likely, the Oberpfalz Forest as well as Southwestern Poland (Sobótka).

SILICICLASTIC MATERIAL

description of the samples

Fragments of eight querns and grinding-stones excavated at Hienheim were investigated in more detail. From seven samples a thin section was made. The majority of the artefacts were made from yellowish to light brownish-yellow quartz arenites that owe their colour to the matrix. The samples are listed in order of increasing grain size: 489 t.s. (medium grain size ca. 0.3 mm), 317 t.s., 414 t.s., 613 t.s. (ca. 0.5 mm), 307, 593 t.s. and 300 t.s. One sample (227 t.s.) is a very different greyish-white banded quartzite with a violet hue.

The properties which appear to differ among the various sedimentary rock samples are the grain size, grain shape and roundness of the grains as well as sorting, matrix content, packing, porosity and mineral constituents. They will be discussed in the next paragraph because only some of these properties can be determined macroscopically or with the aid of a binocular microscope.

Thin section analysis

Those mineral constituents which can be discerned are almost all quartz grains, sometimes with accessory micas, ore minerals, tourmaline and zircon. The quartz arenites are weakly porous and loosely packed; the grains are embedded in a very finely grained to cryptocrystalline (dark)greyish or brownish matrix. Interstitial flow structures are characteristic (fig. 50).

Roundness and sorting of the particles vary from sample to sample. Artefacts 489, 317, 414 and 613 represent sediments with good to moderate sorting; the roundness of the grains varies from sub-angular to angular (fig. 50); the matrix is dark greyish. Samples 300 and 593, poorly sorted sediments with a high matrix content, also include large grains up to 2 mm across. The larger grains are well-rounded to rounded, while the smaller grains become increasingly angular with decreasing grain size. The brownish matrix contains a large quantity of very finely grained quartz (fig. 51).

The quartz particles are monocrystalline or polycrystalline; extinction under crossed nicols is variably undulose. Some of the polycrystalline grains clearly derive from metamorphic rocks (fig. 52).

Sample 227 is a weakly porous (here due to disintegration of certain mineral constituents) quartzite, the undulose particles being closely packed. Where the originally well-rounded grains are in contact, the effects of recrystallization are clearly visible (fig. 53). The resulting fabric is weakly polygonal (mosaic). Parts of the diagenetically recrystallized microcrystalline matrix are still present.

Possible provenance

When the rock types of the quern and grinding-stone fragments are compared with similar rocks cropping out in the area, a striking resemblance is found with the silicified Schutzfels-Schichten (Schmidt-Kaler 1968). These fluviatile kaoline-bearing quartz sands are of Lower Cretaceous origin, the material derives from the Variscan mountain range in the northeast. This deposit is only locally silicified into a compact "quartzitic sandstone", e.g. near Bad Gögging and Sandharlanden, ca. 5 km southeast of Hienheim, and Hagenhill, ca. 7 km to the northwest.

Samples (from C.C. Bakels) of these outcrops were investigated (11 thin sections). Like the artefacts they are quite similar in general appearance but being variable in detail (grain size and shape, matrix, sorting and roundness). The reference material also shows interstitial flow structures in the matrix, moreover the accessory mineral spectra of the artefacts and the reference collection show a close resemblance.

The Hienheim artefacts 489, 317 and 414 in particular turned out to be very similar to the reference samples from Bad Gögging and to a lesser extent Sandharlanden. Artefact 613 is almost identical to one of the Bad Gögging samples, both also have typical lenses of more markedly silicified quartz arenite (fig. 39). The provenance of artefacts 593 and 300 is less certain, although they are still typical of Schutzfels. Possibly the source may have been just northwest of Sandharlanden or near Hagenhill, but the latter deposit is more porous and the intermediate-size grains show better rounding.

The source of artefact 227 has not been found and a former constituent of nearby Tertiary or Quarternary deposits is unlikely.

ELSLOO, SITTARD AND STEIN

AMPHIBOLITIC MATERIAL

Forty-three amphibolitic samples consisting of adzes, adze fragments and rough-outs from Elsloo, Sittard and Stein were investigated macroscopically. Only a few fragments from Elsloo (4) and Stein (4) were available for thin sections. They represent only some of the wide range of variations mentioned in the text below.

Description of the samples

The individual amphibolitic adzes differ in the first place as a result of their structure and grain size (fig. 40). Differences in the colour of the patina may be pronounced, but this is also due to the degree of weathering. The relatively fresh implements display a typical dark olive-green colour, the strongly weathered samples are light greenish-grey.

Differences in structure are more pronounced in comparison with the somewhat doubtful significance of the colour so that the amphibolites were divided macroscopically into six structurally different groups. On the basis of the grain size a further subdivision was made. The groups are composed of the following samples, listed in order of increasing grain size:

I: Si* 163, E* 153, St* 115–1 t.s., E 444 t.s., E 334–1 t.s., Si 98, St 115–2 and E 200
II: St 157, Si 105–1, Si 26, Si 305 (=) Si 307, St 233, Si 198, E 116, E 111 t.s. and E 154 t.s.
III: E 482, Si 64, Si 106, E 388–1, St 52, St 163 t.s.,
E 325, St 48 t.s., Si 105–2, E 452, St 168 t.s., E 337, Si 141 and E 330
IV: E 56, Si 127, Si 97, St 220, E 214, E 210, Si 105–3.
V: E 129 and E 454
VI: E 388–2, E 422 and Si 188

The structural criteria used as the basis for this tentative division are a weakly oriented fabric (I) to a more gneissic structure (II and III), a weak to pronounced layering (III, IV and V) and a weak to pronounced porphyroblastic fabric of relatively larger hornblende and feldspar grains or clusters (II and III). The members of the sixth group are more or less exceptional amphibolites (fig. 40). It should be mentioned that amphibolites resembling the implements of the first Hienheim group were not encountered at the Dutch sites.

Thin section analysis

The mineral composition and petrographic properties of the amphibolites are listed in table 22 (enclosure 8).

Main constituents are *blue -green hornblende*, *quartz*, *feldspar* and *ore minerals*. *Biotite*, *chlorite* and *epidote* occur in variable amounts.

Amphibolites with almost colourless hornblende have not been encountered. Traces of *brown hornblende* may be enclosed in bluish-green hornblende (fig. 54). The textural pattern of hornblende varies between fine-grained clusters with bushy outlines and radial or sheaf-like crystal aggregates (figs. 55 and 57) to

* E = Elsloo, Si = Sittard and St = Stein.

coarser varieties (fig. 56). A less pronounced "Strahlsteinschiefer" pattern is visible in the fine-grained amphibolites. A layering is often pronounced (fig. 59).

Hornblende and also biotite and plagioclase may have developed into porphyroblastic crystals. The orientation of the porphyroblasts is generally at random with respect to the foliation plane (figs. 58 and 59).

Quartz occurs generally as polygonal aggregates, sometimes together with plagioclase.

Possible provenance of the amphibolites

Macroscopically as well as in the thin sections, one may observe some important differences between the Southern Limburg amphibolitic artefacts and those from Hienheim. The very fine grained thinly layered Strahlsteinschiefer amphibolites with irregular cross-cutting veinlets are absent at the Dutch sites. Instead one may encounter porphyroblastic amphibolites which show better crystallization and sometimes well-defined layers (fig. 40).

To decide upon the provenance of these implements is, compared with Hienheim, a more difficult task. No amphibolitic rocks occur within a distance of at least 200 km from the Southern Limburg sites. Van Straaten reports (1946) that only very few and small amphibolite pebbles were encountered in the gravels of the Maas River.

Scholz (written comm.) suggests that some of the Limburg material possibly derives from sources in the Thüringen Forest. Frechen investigated amphibolitic implements from Müddersheim (ca. 65 km southeast of Sittard) and concluded that a Sobótka (Zobten) provenance was in his opinion most likely (Frechen 1965). Later he also suggested the same provenance for amphibolitic artefacts from Elsloo and Stein (Frechen, pers. comm.).

From a geological point of view, in addition to sources along the periphery of the Bohemian Massif, other areas must also be taken into consideration. In the first place the narrow southern strip of the Taunus range and a similar strip in the southeastern part of the Harz, both belonging to the Rhenohercynian zone, should be mentioned. Here very low-grade greenschist facies metavolcanics occur. The basic greenschists of the Southern Taunus may contain the mineral assemblage quartz + albite + actinolite + chlorite + sericite + epidote (Anderle & Meisl 1974); the massive varieties may have been suitable for the production of implements. Low-grade amphibolitic rocks also occur in the Southern Harz; they were quarried in Prehistoric times (Scholz, written comm.). Furthermore nephrite fels and fibrous nephrite, which most probably were used by early man, appear as secondary lenses and veins in close connection with ultramafic harzburgites in the Oberharz (Kluge 1967).

Amphibolites, hornblende gneisses and related rocks are also known to occur in the crystalline basements of the Spessart and the Odenwald. In the Spessart they are found either as scattered relatively small intercalations within the metamorphic basement or concentrated in larger numbers or as larger masses in the northern and southern parts of the complex.

The majority of the amphibolites of the Spessart are of magmatic origin, mafic metavolcanics as well as metagabbros, and consist of (garnet bearing) epidote amphibolites, amphibolite- facies metadolerites (with relics of an ophitic fabric), blastomylonitic amphibolites, chlorite amphibolites (metagabbros) and chlorite-hornblende felses (retrograded peridotites). The metamorphic mineral assemblage of the metabasites consists of blue-green hornblende + plagioclase (20–50%An) ± quartz ± epidote ± pyroxene ± garnet (Matthes & Okrusch 1974).

At the northwestern edge of the complex the most compact parts of a relatively large amphibolite lens were sampled for reference purposes. The main constituents of this amphibolite are a well-crystallized blue-green hornblende showing predominantly parallel orientation and metablastic plagioclase, containing many small inclusions; the latter often show parallel orientation (Si), but are inclined with respect to the general foliation (Se) of the rock (fig. 60). Other constituents of the amphibolite are zoisite, epidote, biotite, titanite, rutile and some ore minerals. The inclusions are mainly small grains of blue-green hornblende and quartz droplets as well as some garnet, epidote, zoisite, titanite and rutile. This amphibolite does not resemble any of the (microscopically) investigated implements from Southern Limburg.

In the Odenwald the metamorphic basement rocks, Precambrian or Lower Palaeozoic, include amphibolites, mainly of (sub)volcanic origin, which are generally concentrated in SW-NE trending zones. The temperature-pressure conditions during the main Variscan metamorphism in the Spessart and the Odenwald are very similar. Metamorphism in the Odenwald also took place under amphibolite facies conditions and the metamorphic mineral assemblage of the amphibolites consists of blue-green hornblende + plagioclase (25–55% An) ± biotite ± pyroxene ± epidote ± quartz (Okrusch et al. 1975). Garnet-bearing amphibolites are restricted to the northeastern part of the region. Effects of contact metamorphism and Late-Variscan retrogradation are present.

From the above it is clear that the majority of the amphibolites in the Spessart and the Odenwald were not suitable for the production of implements.

Finally the Vosges and Black Forest may be taken into consideration. Geologically both areas belong to one complex, divided in the N-S direction by the Rhine graben. In both areas, however, amphibolites are comparatively scarce. There are at present no indications that the Limburg implements came from these source areas.

BASALTIC MATERIAL

The adzes and adze fragments of the second largest group were made from basaltic rock. Twenty-seven samples were available for investigation, 14 from Elsloo (11 thin sections), 6 from Sittard and 7 from Stein (5 thin sections).

Description of the samples

Macroscopically and with the aid of a binocular microscope, the basaltic adzes were subdivided according to structure and grain size. The term structure is used here for the porphyritic habit of the basalts as well as the presence of parallel orientation of the mineral constituents due to flow. Three larger groups, a few smaller ones and several additional individual types can be distinguished. For some groups the subdivision corresponds well with the colour of the patina.

The largest group of basalt consists of samples Si 231, Si 199 (=) Si 354, St 239 t.s., E 185 t.s., Si 251, E 481, E 127 and Si 66 in order of increasing grain size and/or porphyritic habit. These basalts are characterized by a strong porphyritic structure in which well-developed idiomorphic black pyroxenes, sometimes in clusters, are clearly visible together with a hypidiomorphic brownish olivine, always surrounded by a serpentine rim, and ovaloid relics of basaltic hornblende (fig. 41). There are relatively more pyroxene than olivine phenocrysts. A parallel orientation resulting from flow may be pronounced. The colour of the patina varies from light silvery-grey to brownish-grey.

The second group includes in order of increasing grain size and porphyritic habit St 164–1 t.s., E 102 t.s., E 366 t.s., E 63, E 608 t.s. and St 115–3 t.s. These basalts are finer grained, especially the phenocrysts.

A flow structure is only visible with the aid of the microscope. The percentage of phenocrysts varies, and also the relative abundance of pyroxene with respect to olivine. The colour of the patina is more or less brownish grey (black spotted).

The third large group consists of fine-grained basalts with a brownish-grey to greyish-brown colour. At first sight these rocks have a "sandstone-like" appearance. Phenocrysts are hardly visible. Only with the aid of a binocular microscope can one observe a predominance (sometimes marked) of olivine over pyroxene. Flow banding is occasionally visible. The samples in this group are St 129, E 354 t.s., St 164–2 t.s., E 600–1 t.s., E 344 t.s.(=) E 600–2 t.s. and Si 465.

The other basaltic adzes differ slightly to markedly from the three above-mentioned groups in grain size, structure and also colour. These samples are E 389 t.s., a very finely grained basalt with relatively large phenocrysts, St 27, E 398 t.s., St 135 t.s. and E 334–2 t.s.

Thin section analysis

The mineral composition and the petrographic properties of the basalts are listed in table 23 (enclosure 9).

When comparing phenocrysts and groundmass of the basaltic adzes one observes that the differences in grain size are generally distinct, and only in a few of the basaltic adzes is the transition more gradual.

The groundmass consists mainly of the same primary mineral constituents as the phenocrysts, although the relative abundances may vary markedly, e.g. plagioclase.

The main constituents of the basaltic adzes are *(titano)magnetite, olivine, titanaugite, brown basaltic hornblende, biotite, plagioclase, leucite, nepheline,* and some secondary minerals.

(Titano)magnetite commonly displays a well-developed idiomorphism, both the larger crystals and the smaller ones in the groundmass. Size differences are generally gradual (fig. 61).

Colourless olivine phenocrysts may be present as equidimensional crystals or as prisms. This mineral is partly to completely serpentinized (figs. 61 and 63).

Titanaugite, pleochroic in violet and brown, often displays well-developed zoning and twinning. It may occur as individual crystals or in clusters, sometimes together with olivine and/or titanomagnetite (figs. 62 and 63).

Highly pleochroic brown basaltic hornblende occurs in a few adzes (E 185, St 239) as lenticular-shaped bodies that have changed partly or completely into plagioclase, augite, rhönite and titanomagnetite (Frechen 1965; fig. 64).

Biotite only occurs in adze E 389 as rims around around olivine (fig. 66).

Plagioclase is a main constituent in the groundmass of almost all the adzes. It occurs as small laths often in more of less parallel orientation, thus indicating magmatic flow (fig. 65). The small crystals are generally twinned. Only in a few cases are large phenocrysts of plagioclase present. Basalts rich in plagioclase are also known as plagioclase basalts (Frechen 1965).

A few adzes seem to have nepheline as a minor constituent in the groundmass, but two adzes were found to be foid-rich, i.e. the basanites E 334–2 with nepheline together with plagioclase and E 389 with leucite and nepheline (fig. 66).

Possible provenance of the basalts

All the basaltic adzes investigated were made from olivine basalt; almost all contain variable amounts of titanomagnetite, olivine and titanaugite as main mafic constituents and plagioclase usually as the only, sometimes abundant felsic constituent. Foid-rich basaltic rocks were encountered in only two cases (basanites), which possibly may suggest that these rocks were less attractive for use as adzes. The most suitable varieties seem to be the fine grained, moderately porphyritic, compact and plagioclase-rich basalts.

From the map (enclosure 7) it appears that the source rocks are close at hand. Earlier provenance determinations carried out by Frechen using some of the basaltic adzes from the sites in Southern Limburg indicated, in his opinion, outcrops in the Siebengebirge and in one case the Western Eifel (Frechen, written comm.). It is obvious that the most probable source rocks for these basaltic implements are located in the Siebengebirge, Northern Eifel, High Eifel and Western Eifel areas, while the Laacher See and Westerwald areas cannot be excluded entirely.

The presence of (partly altered) basaltic hornblende as a typical mineral constituent in the basalts of the first group is a strong indication that these adzes were quarried near Bad Godesberg on the western side of the Rhine (Lyngsberg, Caeciliënhöhe).

The adzes of the second and third groups and possibly also a few others probably all derive from basaltic rocks from the Siebengebirge area (Oberkassel, Papelsberg, Dollendorf). They may have been quarried from the geologically primary rocks or found as boulders in the (older) Rhine terraces. Only very recently a basaltic boulder resembling the Lyngsberg material was encountered in a Rhine terrace about 12 km north of Sittard.

Sample E 334–2, a basanite with nepheline, shows some resemblance to the Tomberg basanite, 17 km south west of Bad Godesberg. Foid-rich basaltic rocks are not as abundant in the Siebengebirge area as the more silica-saturated plagioclase-rich basalts.

In one case an adze of rather aberrant macroscopical appearance turned out to be a biotite-bearing basanite rich in leucite and nepheline (E 389). It was recognized by Frechen as coming from Gossberg in the Western Eifel, northeast of Gerolstein.

Among the implements from Southern Limburg was one artefact (E 218) made from a doleritic rock with a well-developed ophitic structure. Titanaugite, olivine and plagioclase are the main primary constituents and calcite and chlorite are secondary minerals.

It is not unlikely that the original dolerite was found in the terrace deposits of the Maas River. Dolerites in these deposits originate from the Southern Ardennes (Waterlot & Beugnies 1973).

SILICICLASTIC MATERIAL

Description of the samples

The investigated siliciclastic artefacts from the LBK-sites Elsloo, Sittard and Stein consist of a group of sixteen adze fragments, three quern fragments and several fragments of extensively weathered grinding-stones.

The majority of the adzes were made from weakly metamorphic compact quartzitic rocks, generally displaying a weak schistosity or layering. This group includes three greyish metaquartzites (E 685 t.s., E 684 t.s. and St 153 t.s.), six dark grey to almost black quartzitic phyllites (E 49 t.s., E 71 t.s., E 677, St 167, E 644 t.s. and E 492 t.s.), one black siliceous shale or lydite with a characteristic conchoidal fracture (E 75 t.s.), two dark brown quartz arenites (E 61 and E 477 t.s.), a dark brown siliceous shale (Si L.V.) with an imperfect conchoidal fracture, a quartzitic schist (Si 75), a quartzitic greenschist (St LV) and a strongly weathered biotite gneiss (Si 167).

The three yellowish quern fragments (E 3 t.s., E 40 t.s. and E 57 t.s.) are slightly porous quartzites. The grinding-stone fragments are all quartz arenites which differ in colour and compaction. Three samples were taken for thin sections. Some are reddish-brown due to pronounced limonitization (samples E 11 and E 37); the others are brown to yellowish (samples E 70).

Thin section analysis

Microscopically the adzes differ from each other in the structure and the degree of metamorphic recrystallization, the sizes, shapes and relative amounts of the main constituents quartz, sericite, muscovite, biotite, chlorite, as well as the accessory minerals tourmaline, zircon, rutile and ore minerals, the presence and relative amounts of rock particles and matrix, and the presence of a dispersed dark-brown to black pigment.

The six dark grey-coloured implements owe their colour to a pigment, dispersed throughout the rock but more intensively concentrated in finer-grained bands. The quartz particles (up to 0.1 mm) in the very finely grained matrix are angular. These weakly metamorphic (muscovite and chlorite) rocks were originally banded carbonaceous arenites with a high clay content (fig. 67).

The four lighter grey implements have a higher quartzite content.

The recrystallized quartz particles of E 685 lie in close contact with one another and have irregular (lobate) rims (fig. 72). The matrix of E 685 forms brownish crypto-crystalline siliceous patches. Samples E 684 and St 153 are more schistose with muscovite and chlorite-bearing sinusoidal strings around the quartz particles.

Samples E 492 and E 75 have in common that both rocks are heavily pigmented and very fine and even grained, but they differ in that E 75 is a non-metamorphic black siliceous shale (lydite) with lenses of crypto-crystalline quartz enclosing many small rutile crystals and E 492 is a dark-coloured chloritoid-bearing phyllite (figs. 68 and 69). The prismatic chloritoid metablasts developed prior to the latest deformation.

The dark brown quartz arenites, E 61 and E 477, are layered arenites with coarser grains embedded in a silicified matrix (fig. 70). They seem hardly affected by metamorphism. The majority of the particles (diam. 0.08–0.4 mm) are angular to sub-rounded quartz grains; in addition these rocks contain many rock fragments and newly formed ore minerals (pyrite crystals). Sample Si L.V. possibly represents a similar rock type with a finer average grain size.

The greenish adze fragment, St LV, is a quartzitic schist, consisting of quartz with a variable grain size (up to 0.8 mm), well crystallized chlorite, muscovite and some albite, and accessory tourmaline and ore minerals (fig. 71).

The monocrystalline and polycrystalline quartz constituents of the quartzitic to quartz arenitic querns are closely packed. The contacts are slightly indented and partly straight (mosaic) with only weak traces of recrystallization around the original grain boundaries. The average grain sizes vary between 0.2–0.5 mm.

The majority of the angular (E 37) to sub-rounded (E 70) quartz grains (average grain size 0.2 mm) of the grinding-stones is monocrystalline. Effects of diagenetic recrystallization are incipient and only visible when limonitization is weak.

Possible provenance

The Quaternary terrace deposits of the Maas River contain abundant rock material (boulders, cobbles, etc.) similar to the rock types that were used to make artefacts. Thus a local provenance for at least part of the material is probable and this seems to apply especially for the light-greyish (meta)quartzitic implements and the non-metamorphic quern fragments.

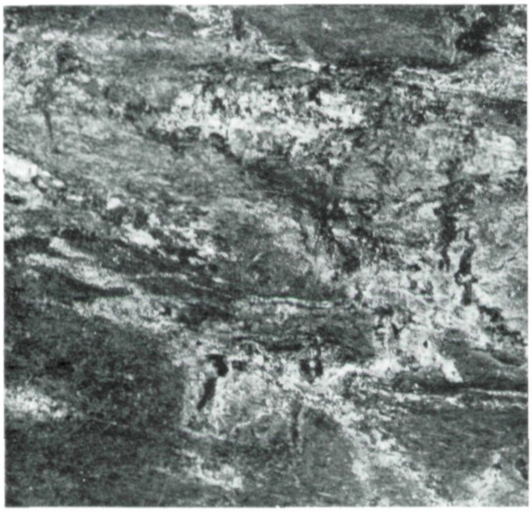
To assume a local source for the dark grey to black coloured adzes, however, is more doubtful since these rocks are quite scarce in the terrace deposits (van Straaten 1946). Moreover, the few small lydite stones encountered in the deposits are devoid of the typical rutile crystal inclusions which were found in the lydite of adze E 75. In the opinion of van Straaten the lydites of the Maas River terraces derive from the Ardennes Massif.

Two specimens, E 71 and E 644 which belong to the group of dark grey implements, were found to compare quite favourably with a similar (reference) rock-type from Horion-Hozémont in Eastern Belgium, where in prehistoric times a workshop was located (Dradon 1967). Although of lighter colour, sample E 49 may have the same provenance.

The chloritoid-bearing phyllite (E 492) must have its primary source in the low-grade metamorphic cores in the Ardennes, south of Stavelot or between Rocroi and Bastogne, respectively (Waterlot & Beugnies 1973).

With regard to the weakly metamorphic quartzitic schists and quartzites an exact geologically primary source is much more difficult to indicate. Greyish to greenish quartzites and grey to dark grey quartzites are known from the lower Palaeozoic of the Ardennes (Waterlot & Beugnies 1973).

The limonitized quartz arenites used for the grinding stones, are derived from locally cemented sands of the Maas River terrace deposits (P.W. Bosch, oral comm.).



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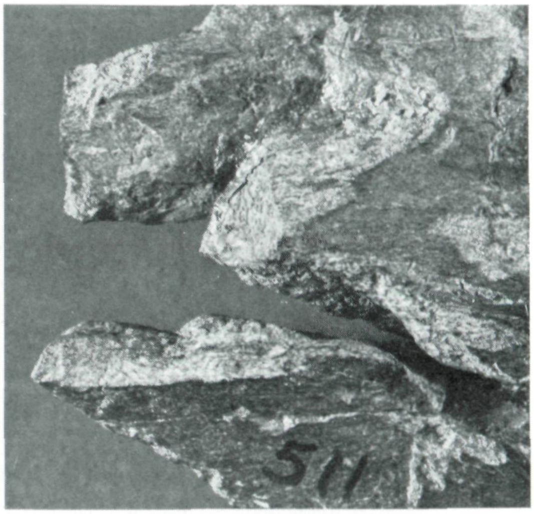

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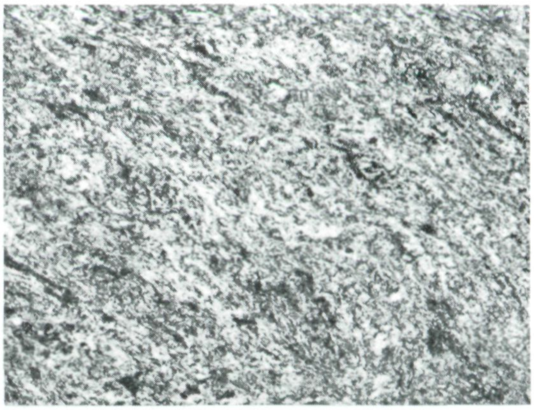

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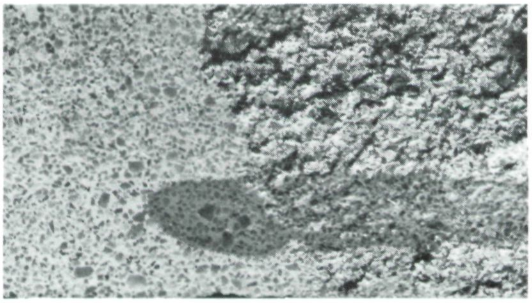

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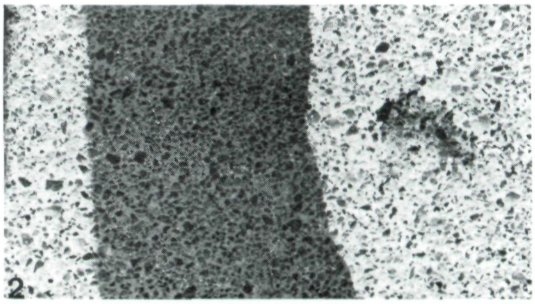

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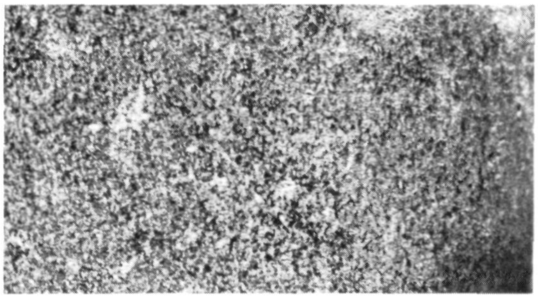
Fig. 38. Macroscopic appearance of four amphibolitic adzes from Hienheim: (a) irregularly banded and a fine polish (H 1089), (b) a splintery fracture (H 511), (c) a linear fabric (H 307-3) and (d) an irregular foliation (H 919). ca 2.5×.

Fig. 39. Quern fragment (H 613) and reference material (Bad Gögging) with light brownish coloured lenses. ca 2.5×.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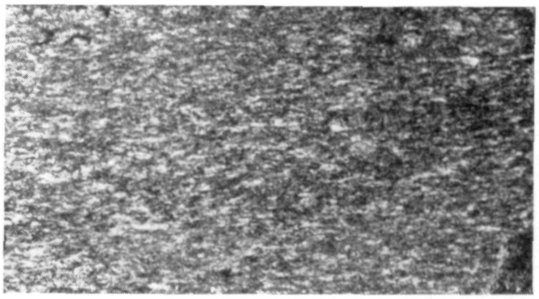
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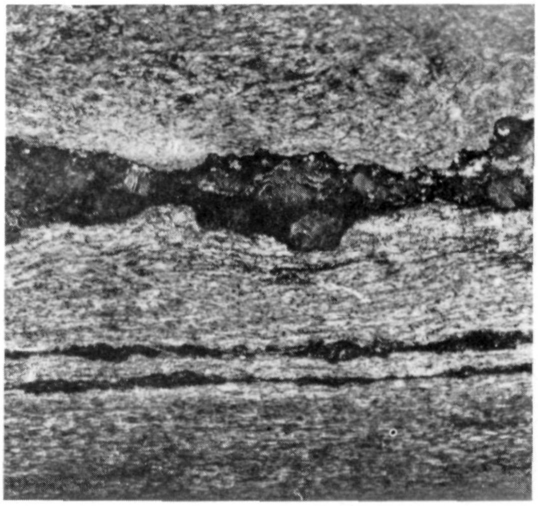
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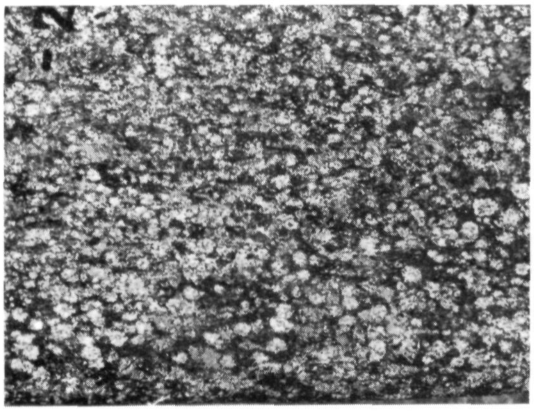
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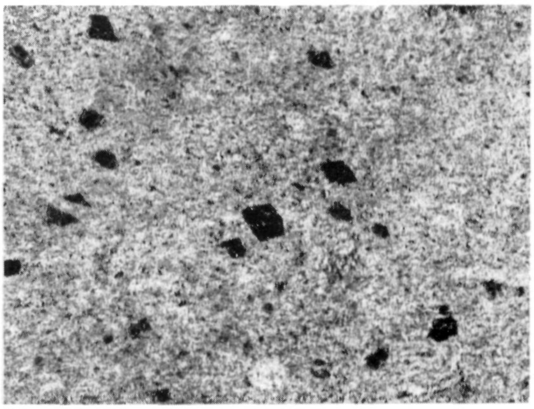
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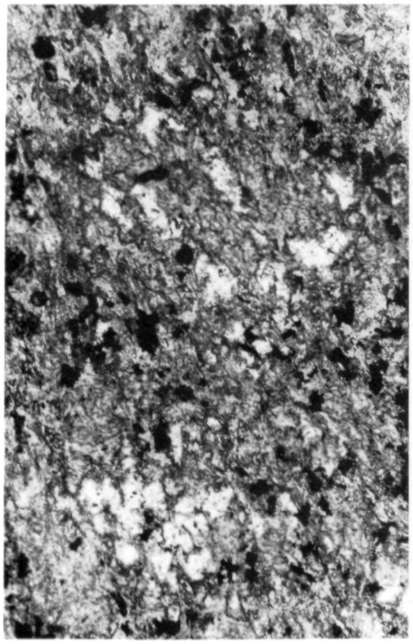
Fig. 40. Macroscopic appearance of four amphibolitic adzes from Southern Limburg: (a) very fine-grained (E 444), (b) a linear fabric (E 116), (c) linear patches (E 452), (d) strongly layered (E 752) and (e) relatively coarse porphyroblastic plagioclase and hornblende (E 388-2). ca 2.5 ×.

Fig. 41. Characteristic surface texture of a basaltic adze from Southern Limburg (Si 66), possible provenance near Bad Godesberg. ca 2.5 ×.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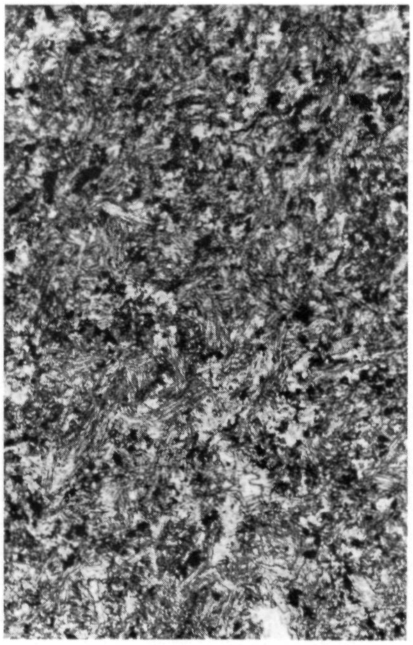
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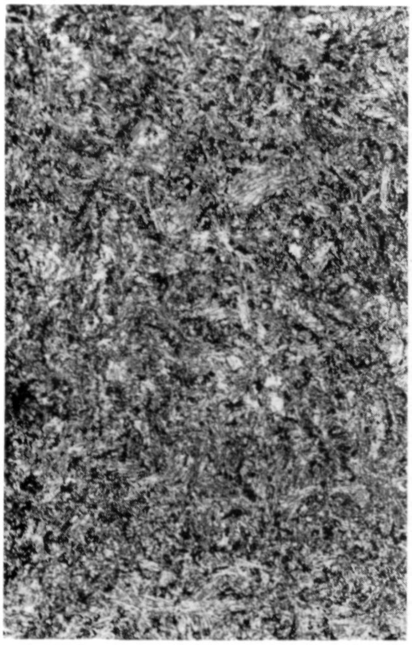
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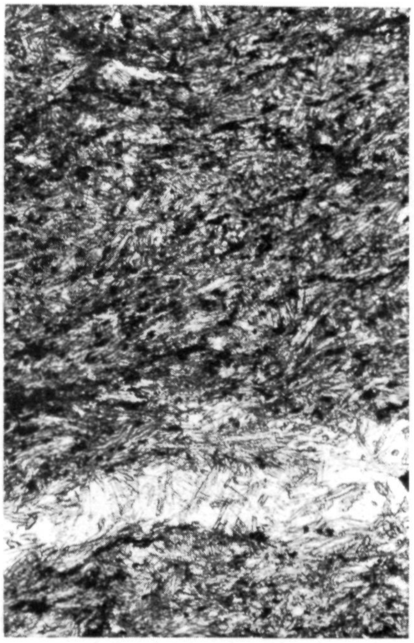
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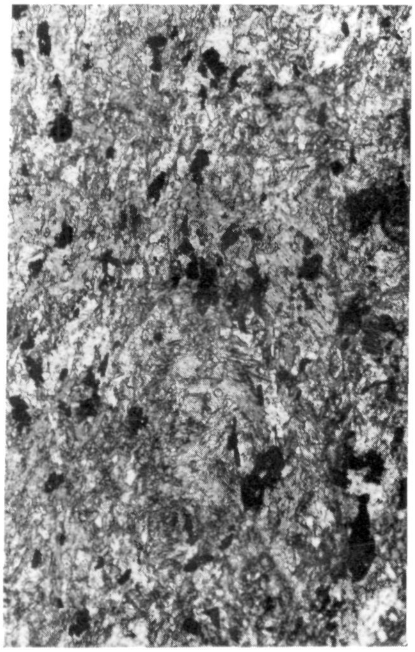
Fig. 42. Amphibolite with microcrystalline bluish green hornblende aggregates with bushy outlines (Hienheim 1083), 40×.

Fig. 43. Amphibolite with relatively coarser blue green hornblende clusters (Hienheim 359). 40×.

Fig. 44. Very fine grained amphibolite with typical "Strahlsteinschiefer" habit (Hienheim 699). 40×.

Fig. 45. Needles of bluish green hornblende penetrating radially in a quartz veinlet of an amphibolite (Hienheim 530). 50×.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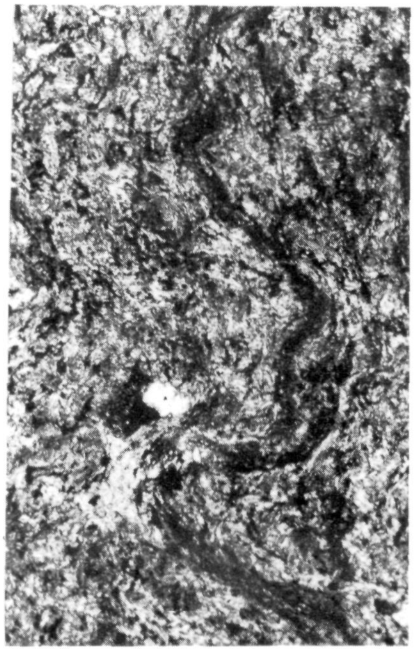
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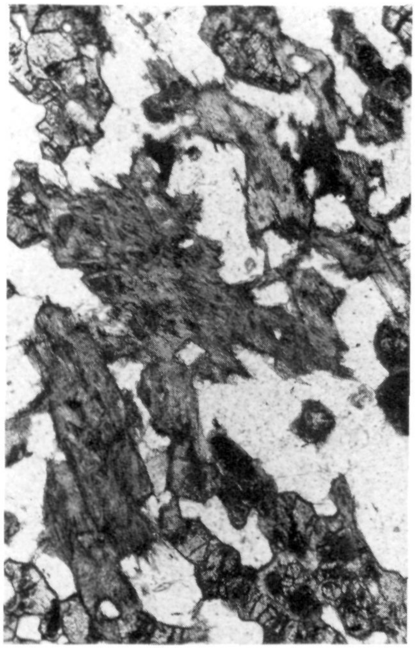
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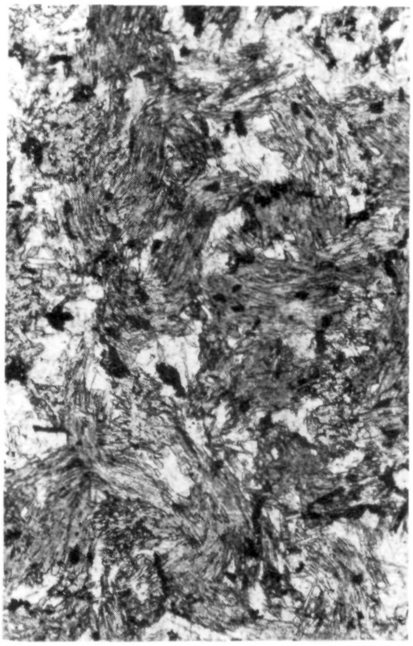
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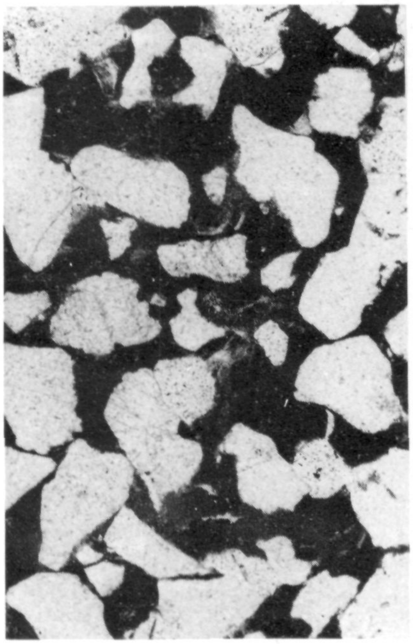
Fig. 46. Porphyroblastic hornblende in amphibolite (Hienheim 1140). 40 ×.

Fig. 47. Finely layered amphibolite (Hienheim 183–1). 40 ×.

Fig. 48. Amphibolitization of gabbro along fractures. Thierling, Regensburger Forest. 40 ×.

Fig. 49. Sheaf-like clusters of coarse grained hornblende oriented at random in amphibolite from Mount Kościusko (Zobten area), Southwestern Poland. 40 ×.



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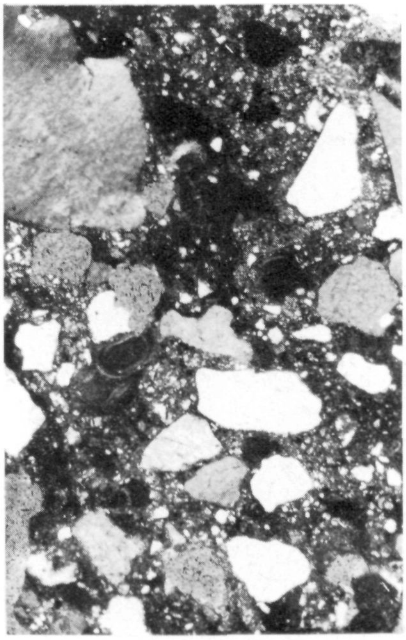

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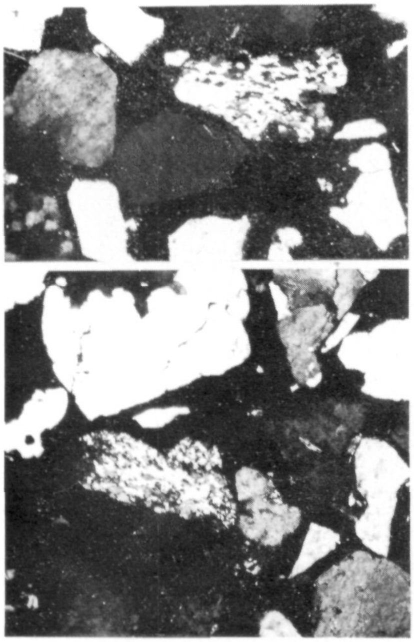

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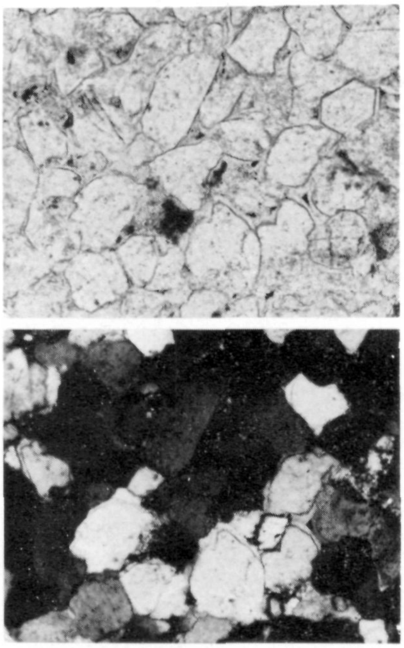

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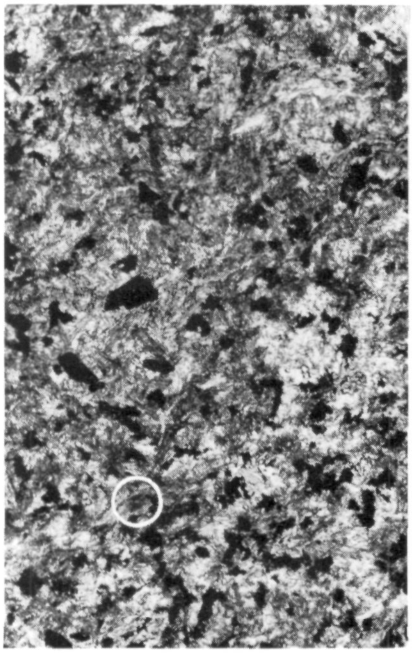
Fig. 50. Moderately sorted, sub-angular quartz grains embedded in cryptocrystalline dark matrix with interstitial flow structures (quartz arenite, Hienheim 317). 40 ×.

Fig. 51. Badly sorted quartz arenite (Hienheim 300) with microcrystalline angular quartz particles in the matrix. Crossed nicols. 40 ×.

Fig. 52. Polycrystalline quartz grains in quartz arenite derived from Variscan metamorphic rocks (Hienheim 613). Crossed nicols. 40 ×.

Fig. 53. Diagenetic recrystallization of a quartzite (Hienheim 227); the contours of the originally sub-rounded particles are still visible. Lower part crossed nicols. 40 ×.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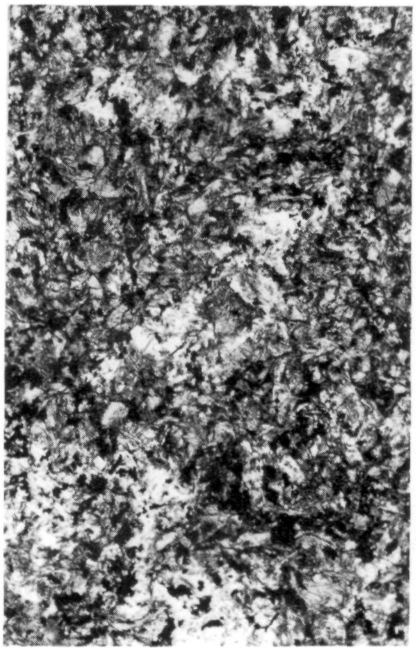
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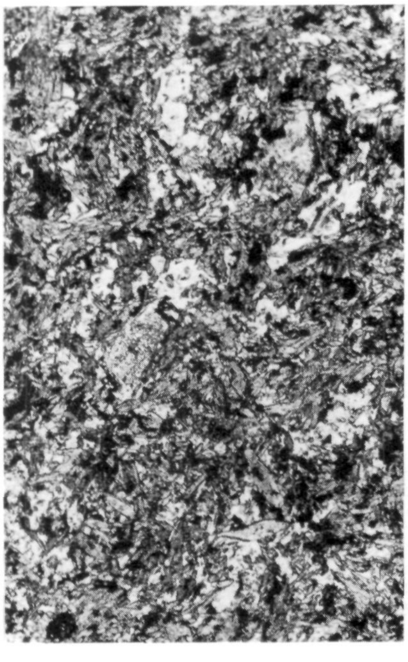
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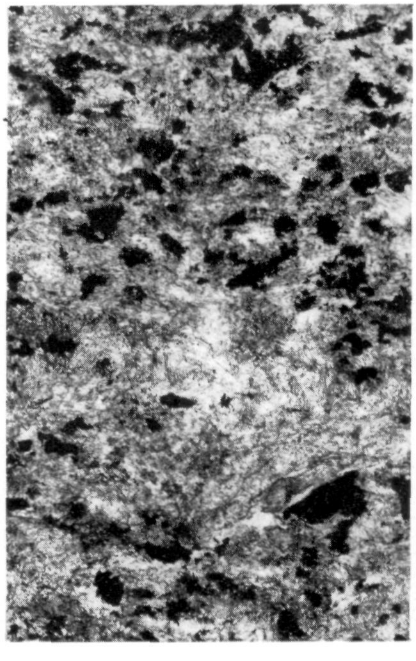
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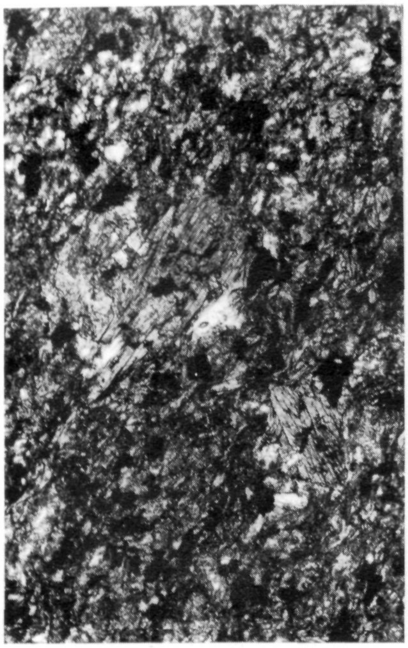
Fig. 54. Amphibolite from Elsloo (E 344–1) with traces of brown hornblende, encircled, within blue-green hornblende. 40 ×.

Fig. 55. Amphibolite with hornblende clusters and sheafs (Elsloo 163). 40 ×.

Fig. 56. Relatively coarsely crystallized hornblende and plagioclase porphyroblasts in amphibolite (Elsloo 111). 40 ×.

Fig. 57. Fine-grained randomly oriented bluish green hornblende needles and sheafs in amphibolite (Stein 168). 40 ×.



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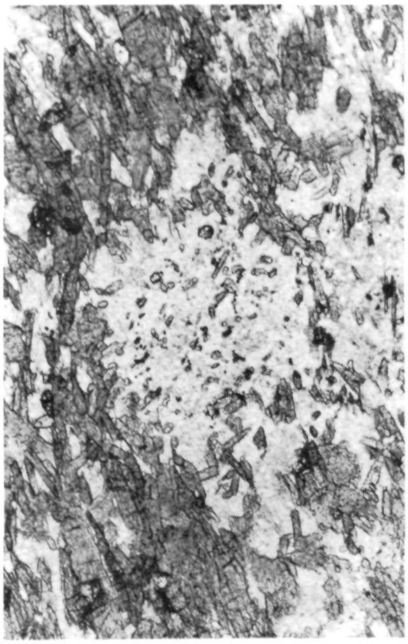

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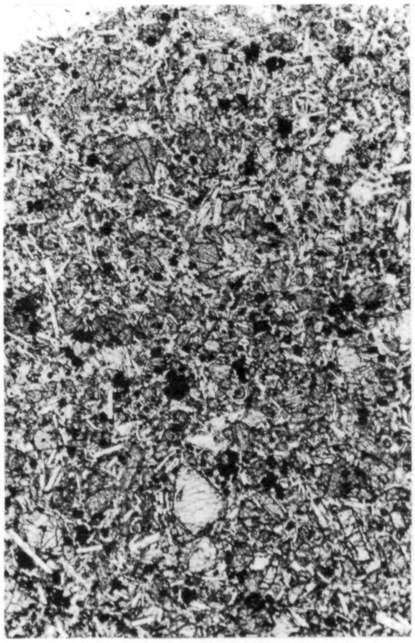

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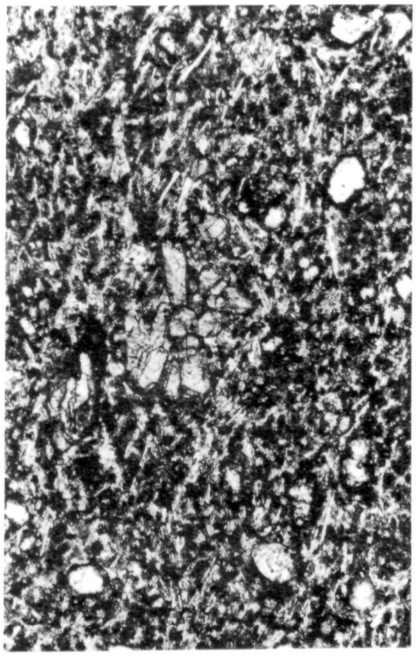
Fig. 58. Amphibolite with relatively large blue green hornblende porphyroblasts (Stein 48). 40 ×.

Fig. 59. Layered amphibolite with relatively large biotite crystals associated with quartz; some biotites are oriented perpendicular with respect to the foliation (Elsloo 334–1) 40 ×.

Fig. 60. Reference amphibolite (Northwestern Spessart) with plagioclase porphyroblast containing inclusions (a.o. garnet). Internal orientation (Si) of inclusions is oblique with regard to external foliation (Sc), 40 ×.

Fig. 61. Olivine basalt with phenocrysts of titanomagnetite in variable sizes, olivine and titanaugite (Elsloo 608), 40 ×.



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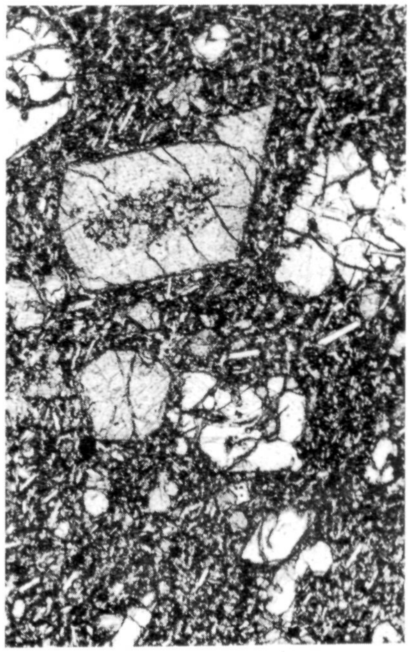

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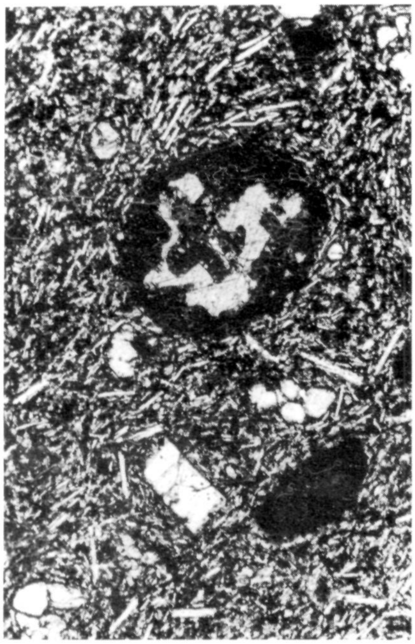

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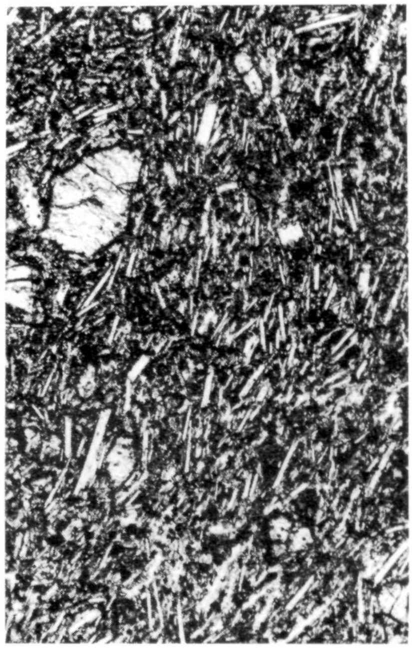

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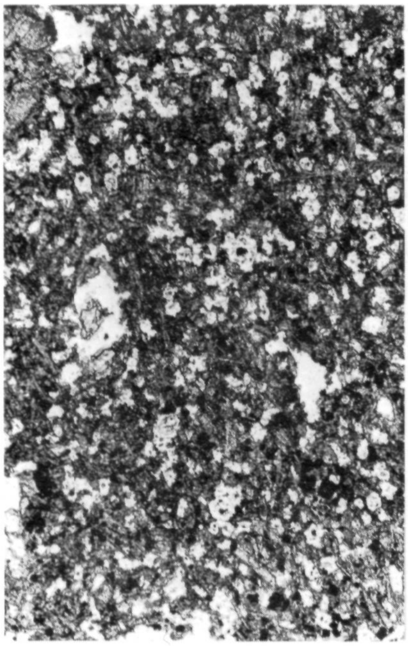
Fig. 62. Olivine basalt with titanaugite cluster (Elsloo 600–1). 40 ×.

Fig. 63. Relatively large phenocrysts of olivine and titanaugite in olivine basalt (Stein 135). 40 ×.

Fig. 64. Olivine basalt with partly and completely altered basaltic hornblende, titanaugite and olivine (Elsloo 239), 40 ×.

Fig. 65. Plagioclase basalt with olivine and numerous relative large plagioclase laths displaying a flow orientation (Elsloo 366), 40 ×.



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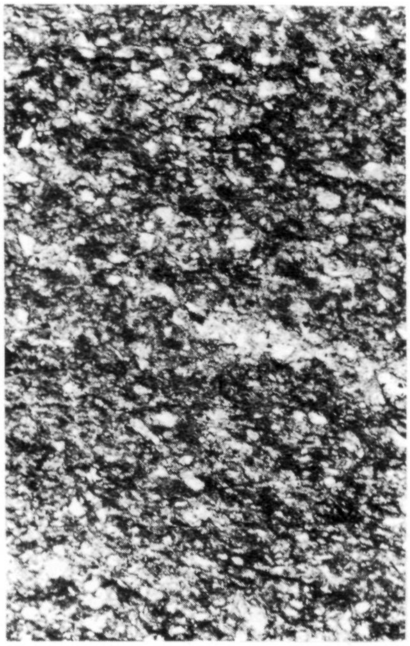

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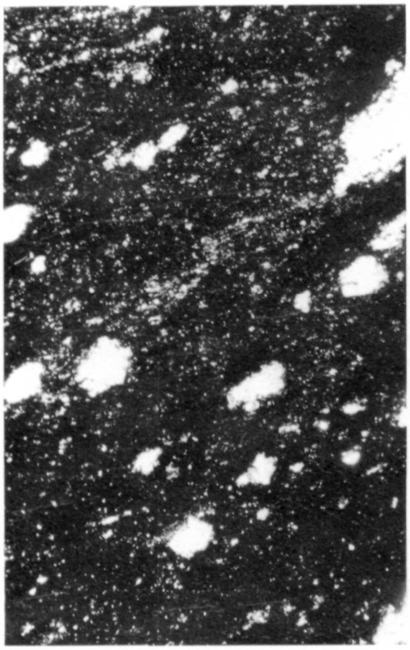

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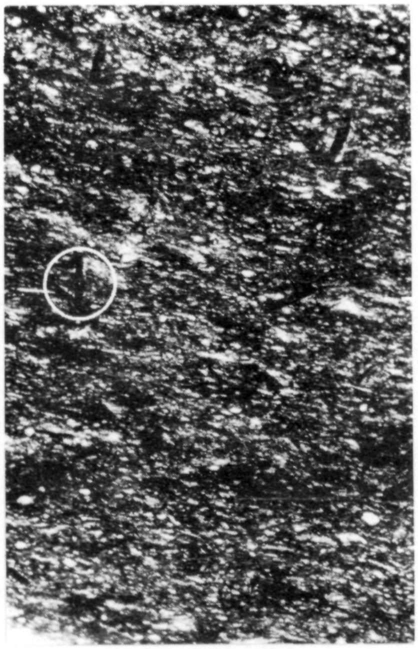

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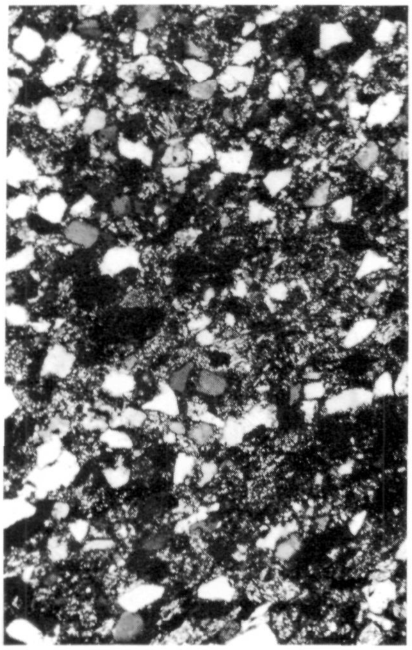
Fig. 66. Basanite, possible origin Western Eifel, with biotite-rimmed olivine phenocrysts and within the groundmass nepheline and equidimensional leucite with a typical inclusion pattern (Elsloo 389), 40×.

Fig. 67. Weakly layered dark brown pigmented compact phyllite, possible origin Horizon Hozémont (Elsloo 644), 40×.

Fig. 68. Typical lydite with microcrystalline quartz clusters (Elsloo 75), 40×.

Fig. 69. Darkly pigmented chloritoid-bearing phyllite (Elsloo 492). Chloritoid is encircled. 40×.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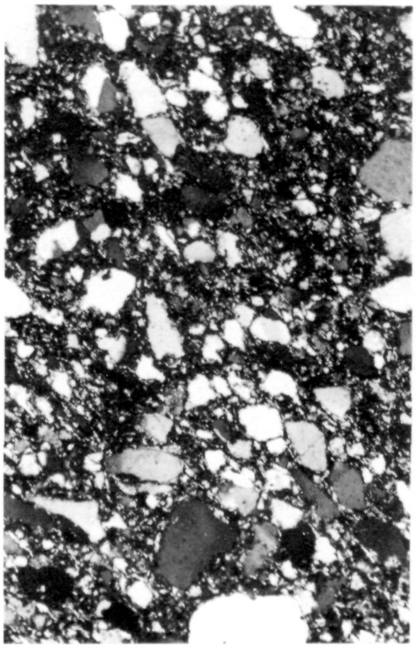
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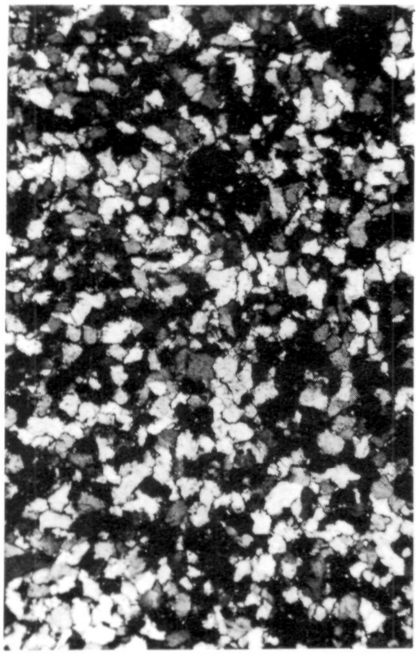
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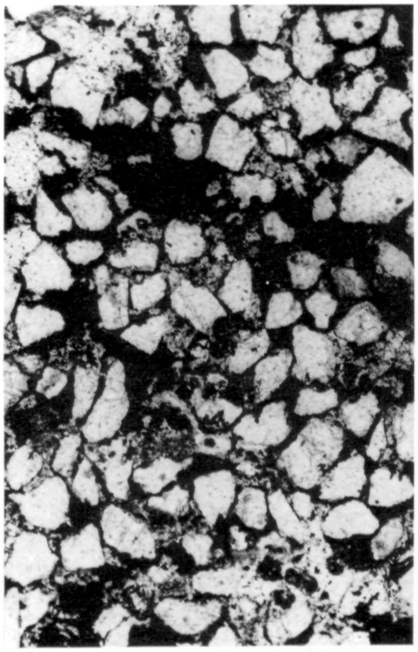
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Fig. 70. Dark brown arenite with a high matrix content (Elsloo 477). Crossed nicols. 40×.

Fig. 71. Muscovite, chlorite and albite bearing quartzitic "greenschist" (Stein LV). Crossed nicols. 40×.

Fig. 72. Fine-grained quartzite with irregular grain-boundaries (Elsloo 685). Crossed nicols. 40×.

Fig. 73. Quartz arenite grinding-stone fragment with limonitic cement (Elsloo 37). Possible source: Maas River terrace. 40×.

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