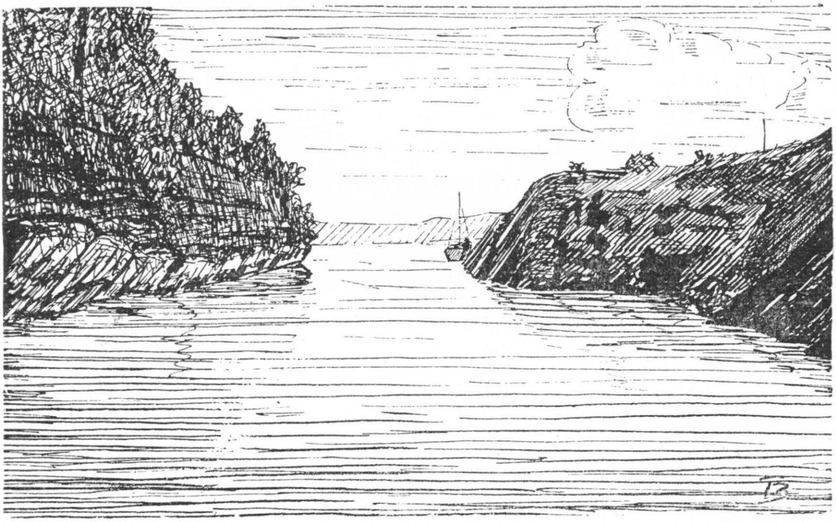

Randesund. (Sketch by T. F. W. Barth)

Geological Reconnaissance of the Area between Kristiansand and Lillesand.

By

Richard V. Dietrich

With text-figure and 2 maps.

Introduction.

The area between Kristiansand and Lillesand, hereinafter called the Randesund Area, comprises the southeasternmost part of Sørland (Fig. 1). As herein delimited, the area is bounded on the west by Topdals Fjord and the lower reaches of Topdals River, on the south and east by the Skagerak, and on the north by Highway 40 between Birkeland and Lillesand. The entire area is about 400 square kilometers.

Before the present study, published geological data concerning the area were limited to the spotting and brief descriptions of five marble occurrences (Holtedahl, 1917, map and pp. 15—17), the spotting of three sulphide showings (Foslie, 1925, map), the spotting and listing of five minor pegmatite masses in the southwestern part of the area (Barth, 1931, pp. 142—143), and complete or partial inclusion on numerous small-scale regional outline maps (see Dons, 1956, pp. 138—140; 142; 144—145). The only published map based on more than cursory spot observations is that of Arne Bugge (1939) which was published on a scale of approximately 1: 220,000 although he mapped the contacts within the area on a map with scale of 1: 100,000. This map includes all of the area under consideration except the islands south of 58°06′N. latitude.

The present study was made in conjuction with my investigation of banded gneisses which are especially well exposed in the southern part of the area. Twentyeight days were spent in the field during the fall of 1958 studying the gneisses and incidently spotchecking Bugge's geologic contacts, measuring and plotting structural elements, and megascopically describing and collecting rock specimens for thin-sectioning and laboratory study. Laboratory work was carried on during the fall of 1958.

Because nearly all contacts within the area are gradational and/or covered, fixing of most of their positions is rather subjective — even at the scale of the map presented. Therefore, although from nearly the outset I did not agree wholly with Bugge's contacts, no disagreements or academic or economic considerations were great enough to make complete remapping of the area seem either warranted or practicable. The map (Fig. 1) consists of Bugge's contacts plus my rock designations and structural symbols.

Acknowledgments.

This investigation was carried on while I was in Norway under the auspices of the United States Educational Foundation in Norway (Fulbright Program). Field expenses were defrayed by Norges Geologiske Undersøkelse. Office and laboratory facilities were made available at the Mineralogisk-Geologisk Museum, Oslo. Professor T. F. W. Barth of the museum suggested the Randesund Area as a base area for my study of banded gneisses, discussed many of the problems involved, and in numerous other ways aided me to carry on the study. Director Harald Bjørlykke and former director Sven Føyn of Norges Geologiske Undersøkelse were most helpful in preparing the way for my accomplishment of many field and laboratory tasks. Many other staff members of the museum and of the survey also were

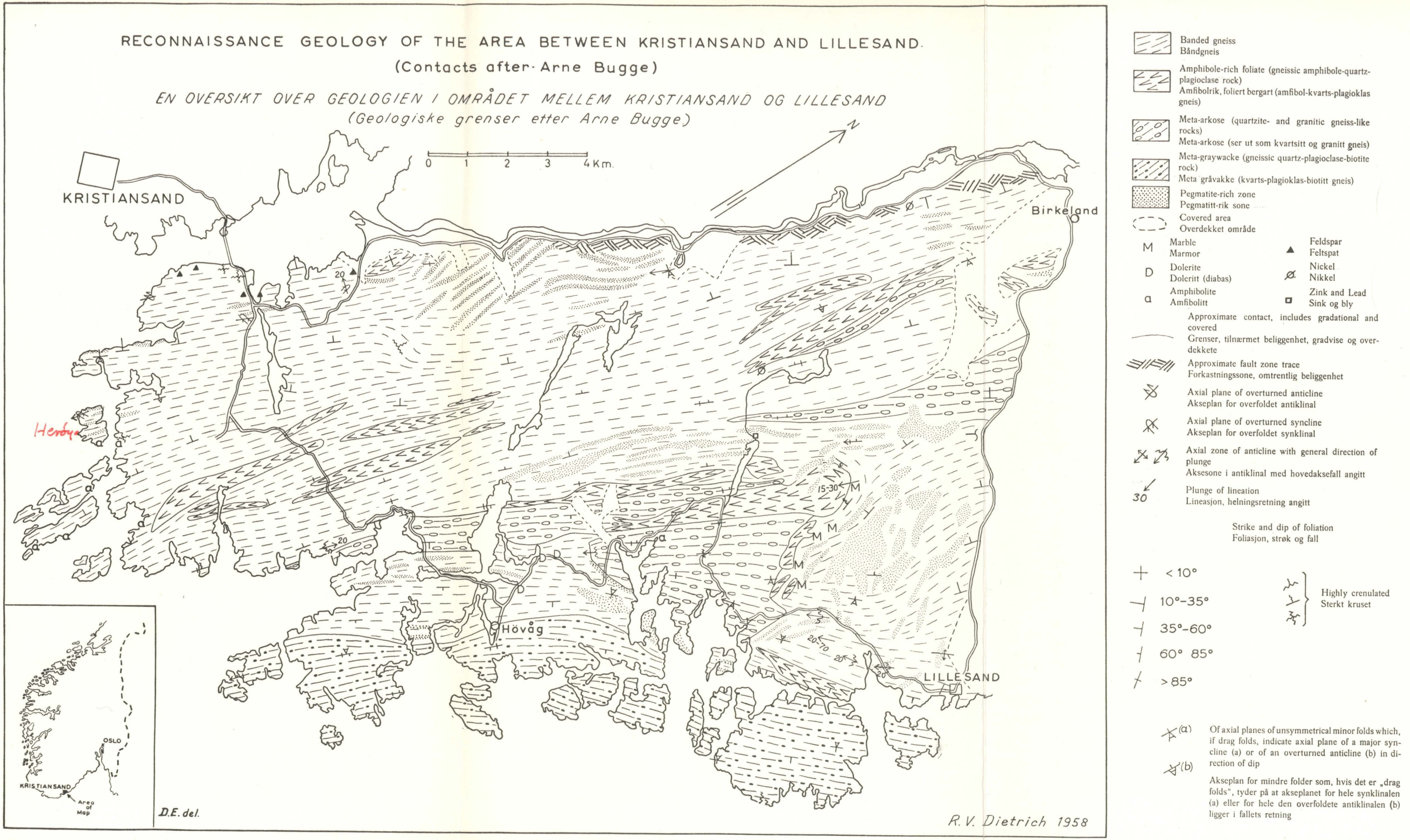
RECONNAISSANCE GEOLOGY OF THE AREA BETWEEN KRISTIANSAND AND LILLESAND.
(Contacts after Arne Bugge)
EN OVERSIKT OVER GEOLOGIEN I OMRÅDET MELLEM KRISTIANSAND OG LILLESAND
(Geologiske grenser etter Arne Bugge)
0 1 2 3 4 Km.
N
KRISTIANSAND
Birkeland
Hövåg
LILLESAND
OSLO
KRISTIANSAND
Area of Map
D.E. del.
R.V. Dietrich 1958
Banded gneiss
Båndgneis
Amphibole-rich foliate (gneissic amphibole-quartz-plagioclase rock)
Amfibolrik, foliert bergart (amfibol-kvarts-plagioklas gneis)
Meta-arkose (quartzite- and granitic gneiss-like rocks)
Meta-arkose (ser ut som kvartsitt og granitt gneis)
Meta-graywacke (gneissic quartz-plagioclase-biotite rock)
Meta gråvakke (kvarts-plagioklas-biotitt gneis)
Pegmatite-rich zone
Pegmatitt-rik sone
Covered area
Overdekket område
M Marble
Marmor
D Dolerite
Doleritt (diabas)
a Amphibolite
Amfibolitt
Feldspar
Feltspat
Nickel
Nikkel
Zink and Lead
Sink og bly
Approximate contact, includes gradational and covered
Grenser, tilnærmet beliggenhet, gradvise og overdekkete
Approximate fault zone trace
Forkastningssone, omtrentlig beliggenhet
Axial plane of overturned anticline
Akseplan for overfoldet antiklinal
Axial plane of overturned syncline
Akseplan for overfoldet synklinal
Axial zone of anticline with general direction of plunge
Aksesone i antiklinal med hovedaksefall angitt
30
Plunge of lineation
Lineasjon, helningsretning angitt
Strike and dip of foliation
Foliasjon, strøk og fall
< 10°
10°-35°
35°-60°
60° 85°
> 85°
Highly crenulated
Sterkt kruset
(a)
(b)
Of axial planes of unsymmetrical minor folds which, if drag folds, indicate axial plane of a major syncline (a) or of an overturned anticline (b) in direction of dip
Akseplan for mindre folder som, hvis det er „drag folds", tyder på at akseplanet for hele synklinalen (a) eller for hele den overfoldete antiklinalen (b) ligger i fallets retning

Figure 1.

most helpful. While I was in the area, Mr. and Mrs. Ole K. Randøy of Kongshavn aided me in many ways.

It gives me great pleasure to acknowledge gratefully all these contributions to the study.

The Rocks.

General Statement. — Nearly all of the rocks of the Randesund Area can be considered representatives of the metamorphic facies generally referred to as the green-schist and the epidote-amphibolite facies. They belong to the socalled Bamble (or Bamle) formation — the use of "socalled" serves to register protest against use of the designation "Bamble formation" — as currently used, the name refers only to the rocks of a geographic district and thus, in my opinion, not only is an unwarranted corruption of the term formation but serves no real purpose. Diverse banded gneisses underlie most of the area. Meta-arkose, amphibole-rich foliates, and meta-graywacke constitute the other units of areal importance. There are also outcrop areas of amphibolite, marble, pegmatite, and dolerite which are too small to be outlined at the scale of the presented map. Nearly all but the contacts between the dolerite and surrounding banded gneisses and between the amphibolite dikes and the banded gneisses may be described best as gradational.

Banded Gneisses. — As mentioned in the "Introduction", the diverse banded gneisses of the area served as the basis of my study of numerous western European banded gneiss localities (Dietrich, manuscript in preparation). Therefore, a brief summary statement concerning them plus mention of a few especially good exposures will suffice for this report.

Banded gneisses are subject to genetic classification as follows:

Relict
- Igneous banding
  - flow
  - differentiation
  - segregation
- Supracrustal stratification

Composite
- Migmatization
  - lit par lit injection
  - differential melting
- Permeation
  - hydrothermal activity
  - pneumatolysis
  - molecular and ionic diffusion

Metamorphically Differentiated
- Mechanical redistribution
- Chemical redistribution

Eclectic
- All combination processes.

Within the Randesund Area are those representative of Relict-sedimentary stratification, Composite-permeation, Composite-differential melting, Metamorphic differentiation — chiefly chemical, and Eclectic — numerous types. Nonetheless, nearly all of the banding seems to owe its existence to an original (Relict) banding — *i. e.*, the unit had a supracrustal origin and consisted of numerous thin beds of diverse lithologies and subsequent changes, some of which have accented the original banding, have been controlled by original chemical and/or mechanical differences.

In the field, many of the gneiss phases appear at natural exposures — especially those awash the sea — to consist of alternating light and dark layers. In fact, cursory examination could easily lead to the misconception that they consist of alternating granitic and amphibolitic layers. Actually, the gneisses are polylithic and are composed of layers of such rocks as would be characterized lithologically (though perhaps not genetically) as quartzite, meta-arkose, meta-graywacke, epidote-rich quartzite, biotite gneiss, biotite-muscovite schist, amphibole gneiss, and magnetiferous quarzite. The layers range from a few grains to several meters thick with the range 2 to 100 mm. most common. The "Relict-sedimentary stratification" type which appears to have gained its present appearance chiefly through essentially *in situ* recrystallization of original sedimentry material is well exposed in the roadside quarry on the north side of the road a few meters west of the bridge across Fidjekilen Fjord, approximately 4.5 km. S.70°E. of the center of Kristiansand. The "Composite-permeation" type is especially well exhibited on the east side and near the end of the point directly north of the island Dvergsøen, approximately 5 km S.45°E. of Kristiansand. Many degrees of permeation are evident at the excellent exposures at this locality. The "Composite-differential melting" type occurs sporadically near the western edge of the area and over into the adjacent area to the west. There are also examples of this type very locally within the outcrop area of the meta-graywacke unit. The "Metamorphic differentiation-chiefly chemical" type is exhibited widely, particularly in conjunction with those best described as being of the "Eclectic" type because of the obvious control of relict stratification over processes that subsequently have accented the banding. Good examples of both of these types may be seen along with the already mentioned types at the first and second listed localities. Actually, nearly all of the main features of the banded gneisses of the area are in evidence at these two fine exposures. Undoubtedly, however, some of the finest exposures that will be available for general viewing within the area in the near future will be those affored by the already completed and yet to be completed cuts along the highway, now under construction, that will connect Kristiansand and Lillesand and go through the heart of the area.

Also worthy of note so far as this unit is concerned are: Locally, the gneisses have concentrations of pegmatite masses and veins — especially good exposures of both the vein type and the irregular type of pegmatites are exposed along the southwestern shore of Gladstad Lake approximately 7.5 km. S.75°W. of Lillesand and in cuts along the now abandoned tramway rightaway about half way between Lillesand and Birkeland. The gneiss contains sporadic veins of chalcopyrite, pyrite, calcite, epidote, green amphibole, and quartz. Some of these same minerals also occur coating joint surfaces locally. None of the veins are more than a few centimeters in thickness. Minor brecciated zones, for example one in which some of the fragments are in a matrix of green amphibole (actinolite-hornblende), nearly colorless chlorite, pyrite, andesine, calcite, and extremely dust-rich feldspar — perhaps metamorphosed gouge, which, along with the fact that some of the fragments are composed in a large part of poikiloblastic actinolite-hornblende, suggests post-breccation recrystallization, probably under metamorphosing conditions (located on the west side of the small westward-extending bay on Fidjekilen Fjord — see above — south of Dvergsnes) and one cemented by quartz which in some parts is present as drusy vug fillings (located at the old lead and zinc prospect pit a few hundreds of meters northwest of Gladstad Lake — see above), are exposed at a few places. Potassium feldspar and even two-feldspar "dents de cheval" that are up to 350 mm. in greatest exposed dimension are abundant locally. At an outcrop near the eastern end of the bridge across Fidjekilen Fjord two small (approximately 2 × 3 × 5 mm.) "dents de cheval" were found that contained yttrium-rich allanite surrounded by potassium feldspar. Another occurrence of metamict (zircon?) was found in the gneisses near Stagenes approximately 9.7 km. S.50°W. of Høvåg. Pre-last metamorphism dikes, now amphibolite, and post-last effective metamorphism dikes, dolerite, cut the gneiss at many localities.

Meta-arkose. — Meta-arkose not only occurs as layers in the banded gneiss but also in units large enough to be mapped separately on the scale of the map presented. Two chief phases plus intermediate types are present. The chief phases are a fine-grained quartzitic-appearing rock and a coarse-grained granitic gneiss-appearing rock. Although some of the outcrop areas of each phase could be delimited individually even on the scale of the map presented, others would not be amenable to such distinction on any but much larger scale maps. In a very general way it can be said that the northcentral belt and the western part of the Kvaase Fjord belt are predominantly of the coarse-grained type whereas the remaining areas are predominantly of the fine-grained type.

In fresh hand specimens the fine-grained variety is buff to pale reddish pink to pale purplish gray and has the typical conchoidal fracture and overall appearance of a vitreous to subvitreous quartzite. Commonly it has certain laminae that are darker in color, because of being relatively chlorite- and/or magnetite-rich, than most of the rock. Locally the rock is massive and apparently homogeneous over thicknesses that are measurable in up to many meters (greater than outcrop dimensions!). Intercalated within this rock are such things as layers that are extremely amphibole-rich and layers that are composed chiefly of chlorite. Pegmatites (some of which are tortuous stringers), quartz veins, and crosscutting amphibolites also occur sporadically within the predominantly fine-grained meta-arkose bedrock areas.

The coarse-grained type has the general appearance of a grayish-pink medium-grained granitic augen gneiss. Its foliation is dependent upon the orientation of the feldspar augen and the fact that both the relatively coarse quartz and biotite, the other chief constituents, are more or less restricted to certain planes. The feldspar augen are pink to salmon colored and most commonly are less than 10 mm. in greatest dimension. The quartz is typically milky to smoky and occurs as the chief constituent of the fine matrix, as larger grains comprising certain discontinuous and irregular bands, and locally as flaser of the same general size as that of the feldspar augen. The biotite, locally chloritized, typically occurs as clusters of grains each of which ranges up to about 3 mm. in greatest dimension. At a few places, *e. g.*, near the crate mill on the shore of Kvaase Fjord near Randvig which is about 5 km. S.40°W. of Høvåg, thin layers up to 15 cm. thick, of the above described fine-grained type occur within this coarse-grained type. Also present within the phase locally, *e. g.*, in the recently completed cuts near Eidfjord which is about 2.7 km. S.20°W. of Høvåg, are segregations, up to 50 mm. in greatest dimension, of chiefly biotite — these, which also occur locally within the fine-grained type within this granitic gneiss phase, give an overall appearance rather similar to that given by small xenoliths or schlieren within igneous granite gneisses.

In thin section, all of the common phases of this lithological type may be seen to consist chiefly of quartz and feldspar (microcline and sodic plagioclase) plus biotite and with or without muscovite, chlorite, apatite, zircon, sphene, magnetite, myrmekite, and calcite. The quartzite-appearing rock may be seen yet to retain relict sedimentary features; the granitic gneiss-appearing rock may be seen to retain no recognizable sedimentary features; intermediate types have sporadic relict features. Preservation of relict features appears to range inversely with present grain size.

Within thinsections of the very fine grained subvitreous quartzitic-appearing type the accessory zircon, sphene, and magnetite occur chiefly as discrete grains that have the appearances of subrounded clastic fragments. Some of the quartz grains also have shapes that possibly reflect original sand grain shapes. Calcite occurs chiefly within certain layers. The layering is best marked by relative concentrations of magnetite and other "heavy mineral" grains. Relatively large grains of chlorite also are more or less similarly concentrated, however, and, thus, where present accent the layering. The chlorite, muscovite, and feldspars all appear to have crystallized (or perhaps recrystallized) within the rock. As mentioned, the chlorite is especially prominent in certain layers. The muscovite occurs as relatively large poikiloblastic grains with sporadic distribution. The anhedral feldspars are microcline, microscopically *non*perthitic, and albite with an anorthite content of essentially zero. The microcline is present in amounts up to approximately 40 per cent whereas the albite has a minimum observed volume of about 10 per cent. All evidence appears to favor formation of this rock by metamorphism of an impure arkosic sedimentary rock. The magnetite, zircon, and sphene occur as relict clastic fragments; the quartz represents partially to completed recrystallized quartz sand; the calcite probably represents recrystallized (?) calcitic sedimentary laminae; the chlorite and muscovite may represent recrystallized admixed sedimentary chlorites and/or clays; the feldspars also may represent recrystallized and metasomatized (potash- and soda-enriched) clays or merely recrystallized sedimentary feldspar fragments.

Within the other extreme phase, the granitic gneiss-appearing rock, all minerals appear to have been crystallized (or recrystallized) within the rock. The chief differences between this and the fine-grained type other than those directly indicated by this statement are: there is biotite (with greenish brown pleochroism) but no chlorite; the plagioclase is An_{12-15} instead of nearly pure albite; the microcline is micro-perthitic; some myrmekite is present. Also noteworthy are relatively large zircon crystals which appear to be in the stages of becoming metamict because although they look quite fresh they have extremely low birefringence — the identification has been checked by x-ray analysis.

If it were not for general spatial association including interlamination with the quartzite-appearing type, it is quite likely that this rock would be called a granite gneiss rather than a meta-arkosic gneiss. As it is, the meta-arkose genesis hypothesis appears to be much more logical an explanation. The differences of An-content of the plagioclases of this and the quarzitic-appearing type may be complementary to the differences in the perthitic versus nonperthitic microcline, *i. e.*, so far as these are concerned the two rocks may be heteromorphic variants dependent upon unlike metamorphic condition recrystallization histories. They are not true overall heteromorphic variants because of marked differences in accessory mineral and overall plagioclase versus overall microcline contents. Under the preferred hypothesis the plagioclase-microcline ratio differences would suggest, by analogy to known arkosic sedimentary basins, that the source area for the parent sediments was northeast of the Randesund area. Alternatively, if the minerals were formed as the result of potash and soda enrichment, differences in travel distances away from a common source because of activation, permeabilities of the rocks, *etc.* might explain the relationships. Here is a most interesting unit that appears to be amenable to really important analyses related to such problems.

Some of the intermediate types show such things as biotite (green pleochroism) and chlorite and intergradational types (?!!) in association and sporadic epidote, quartz flaser, and poikiloblastic (or corroded) feldspar augen as well as less noteworthy intermediate features. In the field the intermediate types may be recognized because of their grain sizes which are larger than that of the quartzitic-appearing types and smaller than that of the granitic gneiss-appearing types.

Amphibole-rich foliates. — Poorly to well foliated rocks that consist of notable percentages of amphibole occur in masses susceptible to separate expression on the map as well as as layers in the banded gneiss. These rocks are called amphibole-rich foliates rather than amphibolites because they contain notable amounts of quartz.

The masses indicated on the map are constitued chiefly by relatively homogeneous nearly black amphibole-plagioclase-quartz foliates. Locally they are banded because of alternating bands with different amphibole-light minerals ratios. At many places the foliation is accented and/or is cut by what appear to be mobilized and segregated quartz and feldspar. In general, these amphibole-rich foliates form more massive outcrops than do the banded gneisses within which they occur.

Thin section studies indicate that the rocks of the units designated amphibole-rich foliate on the map have a much greater diversity of mineral composition than one might believe after megascopic examination alone. Although most of the rocks are composed chiefly of an actinolitic-hornblendic amphibole plus quartz and plagioclase feldspar with little or no biotite, a few phases have biotite present to the near exclusion of amphibole. Further, whereas some of the rocks are nearly completely constituted by amphibole, quartz, and plagioclase, others have notable percentages of magnetite, epidote, sphene, chlorite, and calcite. The amphiboles have shades of green or green and tan pleochroism. They are typically clean but locally contain many small opaque inclusions. Typically those with the numerous inclusions are more irregularly shaped and are associated with more highly altered plagioclase than those essentially inclusion-free. The plagioclases are zoned and with An-contents ranging from about An_{26} to An_{34}. With a few exceptions, plagioclase is present in lesser amounts than quartz. The quartz is strained, commonly in composite grains, and sporadically has sutured borders. Epidote, the most common accessory, typically occurs as scattered small discrete grains. In the phase with the opaque-rich amphibole and the highly altered plagioclase, however, it occurs as relatively highly pleochroic grains nearly as large as the amphibole grains. Magnetite is present as a few well defined crystals in nearly all phases and also as numerous minute grains in certain layers. Calcite occurs as a few scattered grains in many of the phases. Sphene is present sporadically in amounts up to about five per cent. It occurs as irregularly shaped blebs of composite or single grains. A few grains of apatite occur in nearly all sections studied. Chlorite and biotite were found to occur in two sections each. The biotite has a light greenish yellow to nearly colorless pleochroism. The chlorite is everywhere spatially associated with either biotite or amphibole grains. A few grains of perthitic microcline also were found to occur in a couple of sections. These rocks are all foliated with the foliation marked by such things as preferred shape orientation of the amphibole grains and relative concentrations of magnetite, amphibole, and quartz. Some of the phases have crystalloblastic textures. Most have rather nondescript though obviously metamorphic textures.

Rocks of this and similar compositions, when present as concordant masses such as they are within the mapped area, are subject to numerous genetic interpretations. For examples, they could represent metamorphosed pyroxenic-, gabbroid-, or meladioritic-composition igneous rocks (including concordant instrusives, extrusives, and pyroclastics); ferruginous sandy clayey limestones or marls; ferruginous argillaceous dolomites; or dolomitic shales. Further, the metamorphism could have been dynamic plus recrystallization or dynamic plus addition (and subtraction, of course) of materials. To the present, no criterion or group of criteria have been discovered that establish unequivocally one versus other possible origins for the rocks with equivocal field relationships. Although field relationships and megascopic lithological features, *e. g.*, the banding and the quartz content and arrangement, appear to delimit the sill or other concordant intrusive genesis possibility for the masses in the area, nothing more can be ventured without hazard to the present. However, it should be mentioned that in conjunction with my study of banded gneisses (*op. cit.*) spectrochemical studies of minerals of these rocks and of similar rocks of known origins are being made with the hope that geneses may be determined at least within certain restricted categories.

A porphyroblastic (microcline perthite and plagioclase) biotite gneiss that occurs locally as bands within the banded gneiss and in the Randesund area commonly with those closely associated spatially with the amphibole-rich foliate masses is described in this section because of this association plus the fact that the rock occurs in masses too small to be shown on the map at the presented scale. An especially good exposure of this rock occurs about 2 km. west of Kvarenes (approximately 7.5 km. S.50°W. of Høvåg). The rock typically consists of salmon-pink porphyroblasts of microcline perthite with average longest dimension of about 15 km. — 10 to 20 per cent, greenish gray porphyroblasts of plagioclase with average longest dimension of about 5 mm. — less than 5 per cent, and a dark purplish gray fine grained (typically less than 1 mm. in greatest dimensions) matrix of biotite, quartz, and the two feldspars. Thin section studies corroborate this megascopic description and also show that the plagioclase is a low-calcium andesine which has been partially sericitized, that some grains of the microcline perthite exhibit carlsbad twinning, that the biotite is pleochroic in greens, and that the chief accessories are sphene, epidote, calcite, and magnetite. A green amphibole indistinguishable from that of the associated amphibole-rich foliates, apatite, and rounded zircon grains also occur sporadically. Sphene occurs in amounts up to 3 per cent and is remarkable in that some of it is well twinned, some is well zoned, and some of it contains magnetite laths arranged in sort of a triangular fashion. Some epidote grains also exhibit good zoning. An especially significant feature that occurs within some parts of some layers of this rock is what appears to be a gradation between typical myrmekite and typical crystalloblastic texture involving the two feldspars and quartz. Megascopically another gradation of possibly fundamental importance also may be seen — that between this rock and a rock indistinguishable from some of the coarse-grained meta-arkose. Also of possible petrogenic significance is that this rock is similar in appearance to some of the "augen granites" of southern Norway, *e. g.*, the Vegårdshei mass — because of this and because of the relationships between this rock and other lithologies within the Randesund area it appears that this may be the (or at least an) especially good place to start a reinvestigation of the possible modes of origin of such rocks.

Meta-graywacke. — An approximately 2 km. wide area along the eastern side of the mapped area is underlain by a rock unit the overall features of which appear to fit best the interpretation that the unit is a metamorphosed graywacke that may have undergone local anatexis. Especially good exposures of this rock occur on Justøen Island about 8 km. N.35°E. of Høvåg and along the eastern about one-third of the two nearly east-west trending roads north of Høvåg.

The rock is gray on fresh surfaces and buff on weathered surfaces. The rock is medium to coarse grained and consists chiefly of plagioclase, biotite, and quartz. At most places it is well foliated chiefly because of the preferred orientation of the biotite. Locally it is essentially nonfoliated. Some places it is banded as well as foliated because of the presence of quartz-rich layers. As is especially well shown near the east end of the Høvåg road and also on the islands called Ulvøen near the southeastern end of the mapped area, the more homogeneous type grades into the banded gneiss lithology. It is this relationship plus the presence of plagioclase plus quartz-rich bands within the rock proper and also plus the fact that the unit appears to be in structural harmony with surrounding rocks that I have called it a meta-graywacke. Perhaps this designation is ill-chosen because no individual specimen could be, by any stretch of the imagination, so designated. Perhaps something like "gneissic plagioclase-biotite-quartz rock — probably meta-graywacke" would be more congruent with both the appearance and what little is known of the origin.

Studies of thin sections show the rock to be composed of high-calcium oligoclase — 60 to 80 per cent, biotite — 10 to 13 per cent, quartz — 10 to 25 per cent, and minor amounts of microcline, zircon, apatite, sphene, pistacite, and sporadic hornblende. The plagioclase exhibits better development of pericline than albite twinning and is partially sericitized with the thinner twins apparently more sericitized than the thicker ones in some grains. The plagioclase also is zoned slightly and strained and a few grains exhibit the interesting feature of what appears to be restricted induced twinning directly adjacent to some epidote grains. The biotite at some places has brown pleochroism and at others has green. A very few grains are slightly chloritized. The quartz is strained and some of it occurs as composite grains. The epidote is especially abundant in the green biotite type. Some of the sphene grains are of the well developed wedge-shape type. Myrmekite and disseminated grains of calcite have been found to occur in one section each. The nearly complete lack of opaque minerals is also noteworthy. The texture of nearly all types is metamorphic and of some is crystalloblastic. Along this line, of particular interest is the fact that the plagioclase abuts nearly all other minerals (including even sphene), the biotite is abutted by nearly all other minerals, and the microcline where present appears to be of extremely late formation.

The layered type has dark layers essentially indistinguishable from the typical phases and light layers that are nearly biotite-free. The biotite associated with this type has been found generally to be of either the green pleochroic type or something that looks intermediate between the green and brown types — nowhere the typical brown type. A crystalloblastic texture of particularry good development is commonly present in the light-colored quartz-feldspar layers.

As noted above, the origin of this rock is definitely not established. The rock may have originated from the metamorphism of an igneous rock or a sedimentary rock. However, as also noted, I believe the evidence favors the meta-sedimentary origin. The texture of the rock seems to support the field evidence so far as this is concerned. Nonetheless, it seems most likely that the rock did undergo at least local partial anatexis subsequent to its original formation. The name "metagraywacke" should not be interpreted as exclusive but rather as inclusive of all other supracrustal rocks of this general composition!

Marble.[1] — As mentioned in the "Introduction", five occurrences of impure marble within the area — all about 5.5 km. west of Lillesand — were reported by Holtedahl (*op. cit.*). The localities, indicated on the map (Fig. 2) by letter symbol only because of the small sizes of the exposures, are between Bronen and the cascades of Sølberdalbekken. As Holtedahl reported, the marble is impure — typically 80 to 90 per cent $CaCO_3$; it occurs in thin layers — from less than one

[1] Marble has two definitions: commercially, it refers to any calcareus rock capable of taking a polish; petrographically, it is the name given to a completely recrystallized limestone in which all traces of clasticity have been effaced. In this report it is used in the petrographical sense.

meter to a maximum observed thickness of less than five meters; the five exposures may be, but haven't been proved to be, parts of a single lithological unit; the marble has been quarried on a small scale at three of the exposures for use in preparation of burnt lime.

Most of the rock is white or light gray or buff in color; consists of coarsely crystalline calcite (typically 2 × 2 × 2 mm. to 5 × 5 × 5 mm.) — 80 to 98 per cent, discrete crystals and/or masses of crystals of pyrite (most of the crystals are about 1.5 mm. along *a*) — up to 15 per cent in large specimens and up to over 80 per cent in some laminae, and lesser amounts of such minerals as tremolite-actinolite, hedenbergite (variety coccolite), and quartz. Near some of the contacts between the marble and the adjacent banded gneisses, as for example, in the bed of Sølberdalbekken, differential flow (drag) is evident within the marble.

Marble also may occur near Randvig which is about 5 km. S.40°W. of Høvåg. Although no marble was found in place at this locality marble fragments constitute most of the dock fill. It is doubtful that the rock was carried for such usage from any great distance. Inquiries concerning the source also proved fruitless. This marble is associated with amphibolite, is nearly white, consists chiefly of calcite (more than 90 per cent), and also contains hedenbergite, tremolite-actinolite, pyrite, and phlogopite all of which are typically concentrated in certain layers.

As is apparent from these brief descriptions, at least some of the marble is similar to that commonly referred to as skarn. However, the occurrence within the banded gneiss away from any known igneous contact suggests formation under conditions of some sort that promoted "regional" rather than "contact" metamorphism. Alternatively, of course, the third dimension can be considered to hold an igneous mass responsible for the skarn formation. Perhaps, all the "regional" metamorphism is manifestation of metamorphism induced by such a mass. In any case, it appears that this "regional" skarn and associated metamorphic rocks and present or absent underlying magmatic (including migmatitic, anatectic, *etc.*) rocks all point up the many problems relating to the multiplicity of combinations of processes that can be manifest by essentially identical end products. I have often wondered, when pondering such problems at such exposures, if drilling of a few well located deep holes and studying of the cores therefrom wouldn't supply more answers, less equivocal and more economically both time- and money-wise, than extended intensive but essentially two-dimensional field studies which even when followed by good laboratory investigations, necessarily lead at best to unsure guesses for possible answers. The core-drill is, I believe, too much overlooked as a research tool.

Pegmatite. — Granitic composition pegmatite masses of diverse types occur within the area. On the basis of visual estimates, they appear to be most common in the banded gneiss, next most common in the meta-arkose and amphibole-rich foliates, uncommon in the amphibolite and meta-graywacke, and absent in the marble and dolorite.

According to mineralogical composition, all the pegmatites are granitic — they consist almost wholly of feldspar(s) and quartz with or without mica (muscovite and/or biotite). According to aggregation, most of the masses are relatively homogeneous but some show a zonal arrangement of constituents. According to shape of mass, most are irregular or pod shaped but a few are tabular.

Relatively homogeneous tabular masses crosscut the foliation of the banded gneiss and meta-arkose locally. Most are less than 25 cm. thick. A few in the meta-arkose and banded gneiss exhibit the tortuosities commonly referred to as ptygmatic folds.

Some of the pod-shaped masses are essentially homogeneous whereas others are zoned essentially parallel to the walls. Although most of the pods, or lenses, are concordant, some are not wholly so. They range from augen size to masses nearly large enough to be outlined on the map at the scale of presentation. Pods, the relationships of which are well exposed, occur along the southwest side of Gladstad Lake approximately 7.5 km. S.75°W. of Lillesand. Most of the pegmatites of the areas indicated as "pegmatite-rich" on the map (Fig. 2) belong to this type.

Vein type pegmatites, *i. e.,* irregularly tabular masses which were formed as the result of accretionary growth inward from the walls, also occur. Commonly these are roughly zoned with most of the quartz and mica in the central parts of the veins. None of these has been observed to have a central open space. The feldspars and sporadic mica commonly exhibit crystal faces. Both concordant and discordant masses of this general type have been observed with a predominance of the latter. Especially fine examples of this type are exposed in cuts along the now abandoned tramway tracks about half way between Lillesand and Birkeland.

Two features worthy of note so far as pegmatites of the area are concerned are that some of the "dents de cheval" are two-feldspar in composition and for all practical purposes are indistinguishable from small pod pegmatites and that some pegmatites have a definite affinity for zones that once were structurally controlled low pressure areas. The two-feldspar type of "dents de cheval" and one type of structurally controlled zone are well exemplified in the roadcut about 75 m. north of the fish receiving mill about 7.2 km S.65°E. of Kristiansand. A common structurally controlled type in which pegmatite appears to have healed breaks in amphibole-rich foliates is well shown along the shore of the small lake on the west side of the Stangenes road about 9 km. S.50°W. of Høvåg. Another type where pegmatitic material occurs along minor faults of the "Great Friction Breccia" zone is well exposed in roadcuts on the east side of the Gladstad Lake road about. 1 km. south of its junction with Route 40 about 7 km. southwest of Birkeland. That these last-mentioned pegmatites gained their spaces before last movements along the zone is suggested by their being slickensided.

Another extremely interesting feature that may be a pegmatite type or at least related to the origins of some pegmatites is the local development of large grains of plagioclase feldspar and biotite within the meta-graywacke as is exhibited in exposures along the Hellenes road a few hundred meters west of its eastern end (about 3.4 km. directly south of Høvåg). The feldspar grains are irregular to subspherical in shape and range up to 35 cm. in greatest exposed dimension. The biotite grains range up to 25 cm. across. There are many large feldspar grains and few large biotite grains. Both occur surrounded by typical nearly nonfoliated meta-graywacke. This is the only locality where such a development of large grains was observed to occur. Although some of the feldspar grains have thin (less than 2 mm. thick) selvages of concentrated biotite, most do not. Although some large biotite grains at this locality occur with pegmatitic quartz and K-feldspar, none of the plagioclase has been found to be so associated.

Many of the Randesund area pegmatites quite obviously were formed in open spaces and in loci of real or potentially relatively low pressures. The presence of what appear to be isolated pods and lenses suggests formation of at least this type from extremely mobile and tenuous materials. Some relationships, *e. g.*, those associated with the "healed" amphibole-rich foliates, suggest formation from fluids derived by partial anatexis in relatively low pressure zones. The area offers a fine place to study diverse types of pegmatites, their relationships, and their possible geneses. Of particular interest, I believe, is the possibly present series of pod pegmatites — two-feldspar "dents de cheval" — one-feldspar "dents de cheval" — porphyroblastic gneiss. Also worth special attention are the large plagioclase and biotite grains in the meta-graywacke — are these the beginning of some sort of porphyroblast development initial to a pegmatization (?), do they represent an igneous core to a meta-graywacke that really is instead a meta-quartz diorite (?), what?

Amphibolite. — Numerous small crosscutting masses that now are constituted by diverse amphibolites occur within the banded gneiss outcrop area. Another such mass occurs crosscutting the meta-arkose. The best exposed mass is a less than one meter thick dike that is exposed on the east side of the island of Herøen about 7 km. S.35°E. of Kristiansand. The largest mass of this type with crosscutting relationships that are well exposed occurs at the southeastern end of the island of Randøen near the bridge connecting it with Randhl (about 9.5 km. S.50°E. of Kristiansand). This mass does not have so well defined a shape as the Herøen dike. A similar mass, or group of masses, occurs at the shore near Stagenes (about 9.5 km. S.45° of Høvåg). Smaller masses occur near the northwestern side of the channel that trends between the two islands called Randøen and in the small bay just east of Tømmerstø (about 6.5 km. S.60°E. of Kristiansand). The thin tabular mass that locally cuts across the foliation of the meta-arkose is exposed in a new road cut near Kornnes (about 4.2 km. N.10°E. of Høvåg). Each of these is indicated on the map with an "a". It seems likely that other similar masses which have not been observed and recorded to date also occur within the area.[1]

The rocks of each of these masses are amphibolites in the true sense, *i. e.*, they are composed chiefly of amphibole and plagioclase feldspar. The Herøen dike has, in addition to green amphibole and high-calcium oligoclase, about 5 per cent brown biotite, up to 2 or 3 per cent of sphene, and trace amounts of apatite, chlorite, pyrite, and magnetite. The plagioclase occurs as relatively large sericitized grains and as small typically untwinned zoned grains (in mosaic like arrange-

[1] After preparation of the map etching two more were found: one on the south shore of Hoks Lake near Kongshavn and one, which has been deformed and "boudinaged", on the small island southwest of Randøy.

ment). Most of the amphibole and biotite occur associated with each other and forming irregularly shaped aggregates. What looks megascopically like a coarser grained interior of the dike actually is the manifestation of a textural difference between the interior and outside zones of the dike — the dark mineral aggregates are larger and more nearly separated from each other by intervening plagioclase in the central phase. This may be an example of differences in metamorphic textures being controlled by premetamorphism differences — here, most likely chilled versus more slowly cooled zones within an igneous dike. Although the relatively large south Randøen and Stagenes masses have extremely similar appearances and relationships with their surrounding banded gneisses, their rocks are rather different in appearance in thin sections. That both consist chiefly of green amphibole and plagioclase is their only similarity. The Randøen mass rock is highly altered — chlorite, probably after biotite, and sericite with plagioclase are characteristic. The rock also contains up to about 3 per cent magnetite and trace amounts of a greenish yellow epidote. The Stagenes mass rock, on the other hand, is fairly fresh (although there is slight sericitization of the feldspars and some sporadic serpentinization) and contains about 10 per cent brown biotite, about 1 or 2 per cent sphene, and practically no magnetite. Further, the plagioclase of the Randøen mass rock is mid-andesine whereas that of the Stagenes mass is high-calcium oligoclase. Even the textures are quite different — that of the Randøen mass is characterized by relatively large amphibole grains within a mass of extremely fine grains of the same amphibole and intermediate sized plagioclase grains whereas the Stagenes mass rock is much more nearly equigranular. Actually, the Stagenes mass rock is much more similar petrographically to the Herøen dike rock than to the Randøen mass rock. The rock that comprises the thin tabular mass within the meta-arkose also is petrographically similar to the Herøen dike rock. It consists chiefly of green amphibole and high-calcium oligoclase with about 10 per cent biotite and about 1 per cent sphene. An interesting feature associated with this mass is that biotite appears to have been depleted from both the amphibolite and the meta-arkose near the contact between the two. Also, both sphene and amphibole appear to have been introduced into the meta-arkose in a zone up to about 5 mm. thick along parts of the contact. No specimens from the other masses indicated on the map have been seen in thin section.

That the materials which comprise these masses moved into their present positions with respect to the surrounding rocks after those surrounding rocks were formed is obvious. How they moved into place is not so obvious for at least some of them. Except for the Herøen dike, it seems not impossible from the field relationships that some sort of syntectonic mobility other than magmatic mobility might account for the emplacement. Perhaps removal of quartz from amphibole-rich foliates plus plastic flow of the residue might account for at least some. On the other hand, the petrographic similarities between the rocks of some of the masses and that of the Herøen dike may be genetically significant in which case only the south Randøen mass of those studied in thin section would require special consideration so far as emplacement origin aspects. However, even if the masses were emplaced as magma, source of magma becomes a problem. Along with the generally considered sources I would like to suggest consideration of the possibility that such magma could represent the heavier basic materials associated with the anatectically mobilized granitic material (generally considered to underlie the exposed rocks of the area — that is, like those at the surface in the adjoining Telemark area) which sank to a level where they became melted and thus injectible. In any case, all have undergone metamorphism so apparently are Precambrian in age (?!). Further, none appears to be related petrographically to the "older minette" (Precambrian) group of dikes described by Barth (1944) as occurring about 20 km. west of the Randesund area. Therefore, here are representatives of one and possibly two or more other Precambrian basic magma injection periods.

Dolerite. — Three exposures of essentially unmetamorphosed dolerite were found during the present study to occur within banded gneiss near Øresland and Kjøstveid (just north of Høvåg). Their locations are indicated on the map by the symbol "D". These are similar to the masses described by Hjelmqvist (1939) and Barth (1943) and considered to be probably of Permian age. Although the exposures appear to represent three distinct masses, possibly the two northern exposures — those near Kjøstveid — are parts of one mass. The only contacts between these masses and the surrounding gneisses observed were those of part of the southern mass as exposed in the first roadcut south of the Øresland junction. Contact relationships exposed there show that that mass is an approximately 2.5 m. thick dike that dips a few degrees towards the south within banded gneiss with a general dip of approximately 60°SE. Also observable at the same exposure are the facts that the dike has fine-grained basaltic border zones that grade into a coarse diabasic dolerite in the central portion, that there are minor pyrite nodule-bearing zones within the dike that are essentially parallel to the contacts, that associated small cryptocrystalline and/or glassy ribbon injections occur sporadically within the gneiss near the dike, and that there was no (at least no readily apparent) igneous metamorphic effects on the gneiss. Actually, there is an occurrence of garnets, up to 10 mm. along *a* that may be attributable to metamorphic effects controlled by injection of the dike — no similarly sized garnets have been observed elsewhere in gneisses of the area. However, because of the composition of the garnetiferous layer and because of the disseminated arrangement of the garnets within the layer it seems that such a contact or igneous metamorphic control origin is not the likely answer. Subspherical blebs composed chiefly of pyrite and that range up to about 25 mm. in greatest dimension occur throughout much of the exposed rock of the northern mass. Locally these coalesce to form discontinuous layers of pyrite. If these discontinuous layers are parallel or subparallel to the contacts of the mass, as appears quite possible considering the relationship within the Øresland mass, this mass also is nearly horizontal.

In thin section, the chilled border zone rock may be seen to consist of a light yellowish brown, low birefringent, cryptocrystalline material with included numerous subspherical blebs of a darker brown, moderate to low birefringent material, a few scattered masses of aggregates of small 2V, (-) chlorite (?) with crystal outlines (probably in replacement after pyroxéne and/or olivine), and fewer small plagioclase (*ca.* An_{65}) crystals. Toward the center, the subspherical blebs of darker brown material increase in abundance until they form a near continuum with a few scattered and larger than the above mentioned masses of chlorite (?) plus a few plagioclase crystals and fewer skeletal crystals of mainly opaque material. This phase grades to a phase with a less homogeneous matrix that contains many small and a few large phenocryst-shaped masses of the chlorite (?), a few lath-shaped plagioclase crystals, a few skeletal opaque crystals, numerous microscopically discernable but extremely small opaque grains, and a few irregularly shaped masses of what may represent divitrified glass. This phase grades through a more or less typical basalt to the central phase that is a holocrystalline relatively coarse-grained dolerite.

The dolerite is chiefly of intersertal texture with local zones that are subophitic. It consists chiefly of zoned plagioclase (some individual grains are zoned through as much as 30 per cent; albite law twinning predominates over pericline law twinning; highest An-content observed was An_{58} and lowest observed was An_{26}), a high-dispersion clinopyroxene (titanium-rich augite?!), a pigeonitic pyroxene, an amphibole that has green and brown pleochroism, opaque material(s) of both complete and skeletal crystal and dendritic growth types, and aggregates of serpentine plus or minus talc. Some of the plagioclase of each phase appears to have been partially saussuritized. Minor amounts of brown biotite, chlorite, quartz and calcite also occur. The pyrite bleb bearing type appears identical except for the presence of the blebs. These blebs consist of dolerite similar to the typical except for the high pyrite content. The pyrite occurs as large complete or skeletal grains and also as thin coatings along most grain boundaries and some cleavage fractures. There appears to be no indication of depletion of anything from the rock adjacent to or near the blebs. This would appear to suggest that the pyrite was formed chiefly in response to an oversaturation of iron and sulphur in the magma from which the rock was consolidated. More complete investigation is needed, however, to establish the true significance of these. Also considered worthwhile is an intensive study of the remarkably well-exposed Øresland dike from the standpoint of its possibly diverse chemical as well as textural compositions in different parts. Along this line, there very well may be more and even better exposed similar masses which were not seen during my short time reconnaissance of the area.

Another interesting feature associated with the northernmost mass is the fact that the rock has undergone chemical spheroidal weathering to the point that residual boulders of the rock exist beneath a thin mantle over much of the area of which the dolerite is the bedrock. Considering climatic conditions, time of last ice retreat, *etc.* it seems that this may be evidence favoring nonglaciation of the area during at least the last Pleistocene Ice Sheet advance.

Petrogenetic Considerations. — As already mentioned in the description of each major lithological type, numerous problems exist so far as determining true origins and subsequent histories. Some of the chief problems and some of their aspects, possible solutions, and implications are worth restatements.

Barth (1933, pp. 307—309) expressed the view that the rocks of the area could represent the "oldest pre-Cambrian now exposed . . . (the) solid residues after a differential re-fusion with subsequent squeezing out of the pore liquor thus formed", *i. e.*, the solid residue after anatexis and upward removal of solutions to form granitic rocks like those of Telemark. Later, he (Barth, 1947, pp. 9—10) superseded this suggestion, mainly because of "new" structural data, to put the rocks of the Telemark granitic area and the Randesund "less granitized" area in the opposite relative positions before movement along the "Great Fricton Breccia" zone. The latter appears to be a more nearly correct interpretation and more or less "sets the stage" for all petrogenetic considerations of rocks of the area — *i. e.*, they are chiefly rocks of supracrustal origin which subsequently became structurally distorted and metamorphosed at crustal level(s) where conditions similar to those generally ascribed to lower levels existed.

The granitic composition rocks that constitute the relatively large masses herein designated "meta-arkose" and lithologically similar layers within the banded gneiss unit could have had any of a number of diverse geneses. Formation from a magma for any but sporadic zones which possibly may have undergone partial anatexis does not appear to be a likely alternative because of compositions and the presence of relict sedimentary features. Granitization, mainly potash and soda enrichment of a sandstone or essentially isochemical metamorphism of an arkosic sedimentite appear to be the two best possibilities. Chiefly because the diverse types, no matter what their texture, have nearly the same accessory-free compositions I believe the alternative that they formed by nearly isochemical metamorphism to be more likely the correct interpretation. This, of course, suggests that the parent sediment was feldspar-rich which, if true, further suggests derivation of that sediment under conditions of predominantly mechanical weathering and erosion from an area of granitic composition bedrock. I wonder if essentially isochemical metamorphism of relatively feldspar-rich mechanical sediments has not been overlooked far too much as a possible process in considerations of origins of granitic rocks, especially those of Precambrian terranes. Perhaps the lithologies of possible source rocks plus or minus conditions of earlier geologic time favored sedimentation of this general type. Rather straightforward metamorphism without the necessity for wholesale long range movements of materials would then be the only required mechanism to produce some granitic and similar rocks.

Another petrogenetic problem of great importance in the area concerns the origin(s) of the diverse amphibole-rich foliates. This is a problem of interest in nearly every metamorphic terrane of the world. Amphibole-rich foliates — including amphibole gneisses, amphibole schists, amphibolites, and intermediate types — are not only common in most metamorphic sequences but may have any one of many parentages. Therefore, in many cases, if one versus other parentage(s) can be proved, a major step has been made so far as unraveling the geologic history of the entire rock sequence. Little has been done thus far in this study so far as determining the origins of the diverse amphibole-rich foliates of the area. However, from meager beginnings, it does appear that certain investigations of these rocks may be fruitful at least so far as giving checks of the validities of certain previously suggested means for distinguishing between amphibole-rich metamorphic rock types with diverse origins. As mentioned, now underway in conjunction with my investigation of banded gneisses (*op. cit.*) are chemical studies, particularly semi-quantitative spectrochemical trace element studies, of the "pod-type", the dike-types, and various intercalated-within-the-supracrustal-sequence-types of amphibole-rich rocks of the area.

Many of the questions and problems associated with the origin of the meta-arkose also exist so far as genetic considerations of the rock herein designated meta-graywacke. It is not impossible that this rock is a metamorphosed igneous rock. Further, even if it is a metamorphosed sedimentary rock as suggested by the designation employed, it may be that locally it has undergone at least partial anatexis. Although I favor the metasedimentary-plus-local-partial-anatexis possibility for reasons already stated, I am firmly convinced that the unit needs much further study both in the field and in the laboratories — petrographic and chemical — before its true origin can be much more than guessed. Of special interest so far as both the origin of the unit and perhaps pegmatization is the local occurrence of large feldspar grains.

Of the many other petrogenetic problems, solution(s) to which may lie in rocks of the Randesund area, the formation of chlorite by alteration versus original water content of the parent rock control versus progressive metamorphism versus retrogressive metamorphism appears foremost. Although the overall mineralogy of most of the rocks of the area places them in the low epidote-amphibolite facies, chlorite occurs at least sporadically in nearly all of them. In most of them it occurs spatially associated with biotite. In a few, *e. g.,* the meta-arkose, there appears so far as observations through the petrographic microscope are concerned to be gradations from biotites with brownish-green pleochroism colors through biotites with green pleochroism and mineral grains that are neither true biotites nor true chlorites to true green chlorites. Investigations of the biotite-chlorite minerals of these rocks may aid greatly the resolution of some of the many problems related to genesis of chlorite and thus to its true significance or lack of significance in at least certain mineral suites. With rocks of the area as bases such a study could also easily be extended to include considerations of many other questions related to grade of metamorphism versus control by slight differences in original lithology, *e. g.,* recall the possibly heteromorphic relationships of the potassium feldspars and plagioclases of the diverse meta-arkose phases — these relationships may even be amenable to metamorphic grade studies by use of the two-feldspar geothermometer (see, for example, Barth, 1956).

Structural geology.

General Statement. — The geologic structure of the Randesund area and its interpretation constitute the ingredients of what perhaps might best be termed, in the vernacular, a geologist's nightmare — the structure is complex; exposure is poor even though outcrops are numerous. Actually, the area is quite exemplary of the futility commonly met where "it is not economically worthwhile to map that area on anything but a large scale".

The complexity, although quite obvious from nearly the beginning of the field work, became most apparent when certain interpretations had to be changed rather markedly to account for features exposed at a few new roadcuts which were completed late during the field season. Two things standout: 1) at least part of the rocks have undergone movements in the socalled "flow zone" and, 2) even major structures may be overlooked because of the lack of merely a few meters of exposures. The possibly ambiguous statement in the preceding paragraph concerning numerous outcrops versus poor exposure has three main facets: 1) most of the outcrops are obscured by thick lichen covers; 2) large glacial erratics and slumped blocks are commonly indistinguishable from bedrock; and, 3) many "critical" areas are covered by swamps, lakes, *etc.* The difficulties of mapping such an area on any but a scale of *ca.* 1:100 is obvious. Equally obvious, however, is the lack of present day economic justification for mapping it more exactly than on a scale nearer *ca.* 1:100,000. To multiply difficulties, no proved-to-be-valid geopetal features were found to occur. Reconsideration is also necessary here of the fact that I spent so short a time within the area that my percentage observed of even good exposures must have been low.

Of primary importance to all structural considerations concerning the Randesund area is determination of the correct answer to the question "are foliation and original bedding coincident with each other?". The answer employed is that they are except very locally where it is obvious that they are not. This interpretation is used mainly because of the fact that foliation and compositional breaks are parallel to each other nearly everywhere where they have been observed within the area. This is true even where it appears that the main foliation is a manifestation of some sort of mechanical streaking. Nearly all of the foliation strikes within a few degrees of N.25°E. In the western approximately two thirds of the area most of the foliation dips moderately to steeply towards the northwest; in the eastern about one third of the area most of the foliation dips moderately to steeply toward the southeast. Exceptions occur, however, in many small areas. Perhaps the most noteworthy of these is the area along the "Great Friction Breccia" zone which crops out sporadically along the western side of the Randesund area near the Topdals River. Within and near this zone strikes and dips of nearly any named combination can be found to occur. Other areas where other than the typical regional strike and dip occur are interpreted as crossfolds, as dragfolds, and as near major fold axes. Only the fold herein called the Kjellingland anticline can be listed as a relatively well defined major fold within the area. Although other similarly sized structures may exist, none has been proved. The fact that drag folds are commonly subject to more than one interpretation so far as position in relation to larger structures is of major concern. Also of importance along this line are questions concerning aspects of chevron versus isoclinal folds and whether or not open folds and isoclinal (or chevron) folds are likely to occur together in a relatively small area even if formed at different times. One of the most obvious group of features of the region is the topographic alignments for which a structural control interpretation is evaluated. Lesser features, size-wise, such as slickensides, boudinage, joints, and alignment of "dents de cheval", add to the overall structural picture.

Great Friction Breccia. — The zone in the Randesund area that is considered to be part of the "Great Friction Breccia" is exposed sporadically along Topdals River. The zone is nearly, but not quite, parallel to the strike of the foliation of the adjacent rocks. At most of the exposures examined this "rock" is not what is commonly considered to be a fault breccia. Rather, it is a zone that consists chiefly of such features as chaotic strikes and dips of foliation, numerous close-spaced joints, an abundance of slickensided surface, minor faults (typically pegmatite-filled), and some mylonitized rocks. Many areas along the zone are covered with angular rubble fragments, each bounded by at least a couple of slickensided surfaces.

The only features seen within the area that appear to bear directly on interpretation of the directions of relative movements of the blocks on either side of the zone suggest that the eastern block moved downward with respect to the western block. These are the general change of dips within the zone and relationships exhibited by minor faults in a roadcut along the eastern side of the Bordhaugen—Vallesvær (Gladstad Lake) road a few tens of meters south of its junction with Route 40 (approximately 7 km. southwest of Birkeland). The dips within the zone tend to be low and to the east — no matter upon which side these occur, considering the regional northwestward dip, if they represent drag effects, they indicate relative downward movement of the eastern block. The minor faults, the relationships of which are extremely well exposed corroborate this interpretation. They also suggest that the fault zone dips toward the southeast.

Other Faults. — Minor brecciated zones such as the calcite- and meta-gouge (?) -cemented one mentioned in the section "Banded Gneiss", mylonitic zones, and zones of concentrations of slickensides occur sporadically within the area. That some of these zones appear so small and isolated suggests that they may be merely expressions of the commonly overlooked fact that competency of a rock is an extremely critical quality that ranges greatly both temporally and spatially. As is mentioned in a succeeding section, numerous alignments also occur. At least some of these may represent more than minor offsets. The approximately N.35°E. trending alignment that is between the mainland and the eastern islands and the approximately N.75°W. trending one that contains Drangs Lake (about 7 km. east of Kristiansand) have been so interpreted (Barth, 1956, p. 30). Although these and similar features may be expressions of faults, no evidence difinitely supporting this has been observed during this study. Perhaps the former one merely expresses the bedrock area of a relatively non-resistant rock.

Kjellingland Anticline. — The structure herein named Kjellingland anticline because the axial zone is especially well exposed in cuts near Kjellingland, which is located about 3.5 km. S.65°W. of Lillesand, is the largest well-delineated structure within the area. Both limbs dip moderately to steeply away from the axial zone. The axial zone corresponds with the westernmost belt of meta-arkose and on-strike banded gneisses at the present level of erosion. The rock units on either side of the central units do not match well lithologically. The fold plunges to the south with culmination north of the mapped area and depressional low not definitely located.

The belt of amphibolite with bedrock pattern of elongate drop shape that occurs directly west of the axial zone meta-arkose appears to be a synclinal salient on the main fold.

The area directly west of or that covered by the Kvaase Fjord may be a southern extension of the fold. To the west side of this area the foliation dips steeply to the west to nearly vertically whereas to the east it dips towards the east. However, where horizontal foliation and/or strikes notably different from the general strikes of the area should occur, only vertical and near vertical foliation with strikes similar to those of the rest of the general area was found to occur except locally — the possible exceptions observed occur near Randvig, about 5 km. S.40°W. of Høvåg; at the shore on the point south of Grønevold, about 7 km. S.40.°W. of Høvåg; and, at the shore near the Isefjær road—Randesund to Lillesand road junction, about 35 km. S.80°W. of Høvåg, where concentrations of minor folds occur. In any case, if this is the axial zone of a continuation of the Kjellingland anticline, there are unaccounted for complications. If not, there must be present some other large structure such as a fault or an overturned syncline to account for the relationships. The anticline-plus-complications possibility appears to be the more logical interpretation in light of the presence of the recognized anticline in nearly the same strike belt to the northeast.

Other Fold Features. — Although the Kjellingland anticline is the only major fold recognized within the area, it seems quite likely that others exist. The alternative that the northwestward dipping rocks of the western approximately two thirds of the area represent an essentially homoclinal sequence with thickness of about 7500 meters is unlikely. As is shown on the map, numerous small folds are present. Unless these are given some farfetched (?!) interpretation such as their representing relict sedimentary slump structures, they must be of tectonic origin and probably are drag folds. Nonetheless, it seems premature to use them for structural interpretations until much more intensive field work is carried on in the area. Among other things, some may be drags on larger drag folds and, therefore, possibly misleading so far as interpretation of large scale structures, *e. g.*, an observed minor fold might be on the overturned west limb of a larger drag anticline on the east limb of the major anticline. Another possibility would seem to be that the minor folds are restricted to or at least more abundant near the axial zones of the larger (major) structures. If this could be shown in subsequent studies to be true and perhaps a regional habit, it would be invaluable to structural interpretations. Yet another possibility is that the folds are at least locally steeply plunging at the present level of exposure and that merely extremely local strike differences serve to show where their axial zones are — finding the locations of such would require much more intensive field mapping than that done during this reconnaissance!

These possibilities give rise to questions concerning what type(s) of large fold(s), if any, may be present. If the smaller folds are replicas of the larger structures — as has been reported for many areas throughout the world — it would appear that at least some of the larger structures are essentially isoclinal folds. B u t, is this possible considering the fact that the one proved major fold of the area is not isoclinal but fairly open, *i. e.*, is it likely that both open and isoclinal folds exist within a relatively small area? Perhaps a correct compromise would be open plus chevron folds. On the other hand, perhaps two or more periods of tectonism resulting in folding accounts for the relationships. The following areas, along with some of those mentioned in the preceding section, will be of special interest so far as future investigations of these problems: 1) on the mainland at the shore a few meters south of and opposite the northeastern end of the island Kjellevige — approximately 2.5 km. S.80°E. of Kristiansand; 2) on the south side of the Kristiansand—Randesund road a few tens of meters southeast of Beines — approximately 5.5 km. N.75°E. of Kristiansand; 3) on the southwestern side of the island of Herøen — approximately 6.3 km. S.35°E. of Kristiansand; 4) near Gras Lake — approximately 10 km. N.25°E. of Kristiansand; and 5) near the abandoned fortifications on the southeast side of the island of Justøen — approximately 6 km. S.15°W. of Lillesand. Another approach to these problems will be the thorough investigation of the aforementioned diverse types (and aged) mafic dikes with emphasis on their relative distortion, cataclasis, reconstition, *etc.*

Also of interest so far as folding is concerned are crossfolds. A well exposed crossfold occurs in cuts along Route 40 approximately 7 km. N.55°E. of Kristiansand and on outcrops both east and west of these cuts. The axial zone of the fold appears to trend about N.75°W. and nearly perpendicular to the strike of the local foliation. Other crossfolds were observed to exist. Perhaps some of the alignments (see a succeeding section) are expressions of such crossfolds rather than joints or shear zones. On the other hand, until such crossfolds are found farther away from the "Great Friction Breccia" zone than those thus far seen, the alternative that they are but features formed consequentially to movements along that zone cannot be completely precluded.

Joints. — Numerous joints occur throughout the diverse rocks of the area. A few of them have been filled subsequent to their formation— some quartz veins, pegmatites, and the one well-exposed dolerite dike can be seen to fill joint fractures; many are pyrite coated. Of the numerous diversely oriented joints measured, three sets predominated the readings: N.65°—85°E. with dip within a few degrees of the vertical, N.45°—60°W. also with dip within a few degrees of the vertical, and nearly horizontal. Locally, as near Kvarenes (about 7.5 km. S.50°W. of Høvåg) a N.70°—80°W. set with dip of about 60° to 70°NE. is present.

Alignments. — The term "alignment" as used in this section can be defined as any distinctly linear topographic feature. The map, Figure 2, was constructed from aerial photographs by plotting all obvious linear features other than those known to represent foliation. General foliation trends are indicated by the two dashed lines. Plewe (1952) similarly constructed a diagram for much of southern Norway but also included most strike alignments.

As is readily apparent, two sets of alignments predominate — one that trends approximately N.50°W. and another that trends about N.70°—80°W., nearly perpendicular to the trend of the foliation. Nearly all, if not all, of these alignments are erosional and only, if at all, consequentially depositional. Therefore, they must be expressions of some bedrock feature(s). Faulting appears to be an unlikely answer for at least most of them because, as shown by Bugge's contacts, lithological units are not displaced — further, because dip values range over many degrees in the area, even the possibility that all movements were dip-slip with no strike-slip components is an unlikely if not completely impossible alternative interpretation. Joints or shear zones of essentially no resultant offsetting movements seem to be a much more logical answer. Reëxamination of a few of the alignment areas after the map was prepared failed to yield any conclusive answer — although there are joints of the correct orientations in some of the examined areas, similarly oriented joints also occur in non-alignment areas. Abundance of joints does seem to be greater in at least some of the alignment than in the nonalignment areas but this I consider too subjective to use as anything other than permissive evidence until some areal statistical studies can be made. Nonetheless, I do favor the possibility that at least some of the alignments express zones of relatively high concentrations of joints. As mentioned in a preceding section some also may express crossfolds. The orientations of the alignments considered in conjunction with the orientation of fold axes and general regional strikes of foliation suggest numerous possibilities. For example: 1) the two chief sets may constitute a conjugate set, or system, of joints formed as the result of forces that could be resolved to compression along axes that trend approximately N.35°W. — perhaps, if this were the case, of the same forces that were responsible for some of the folding; 2) the set which is nearly everywhere essentially perpendicular to the general foliation may represent the results of appli-

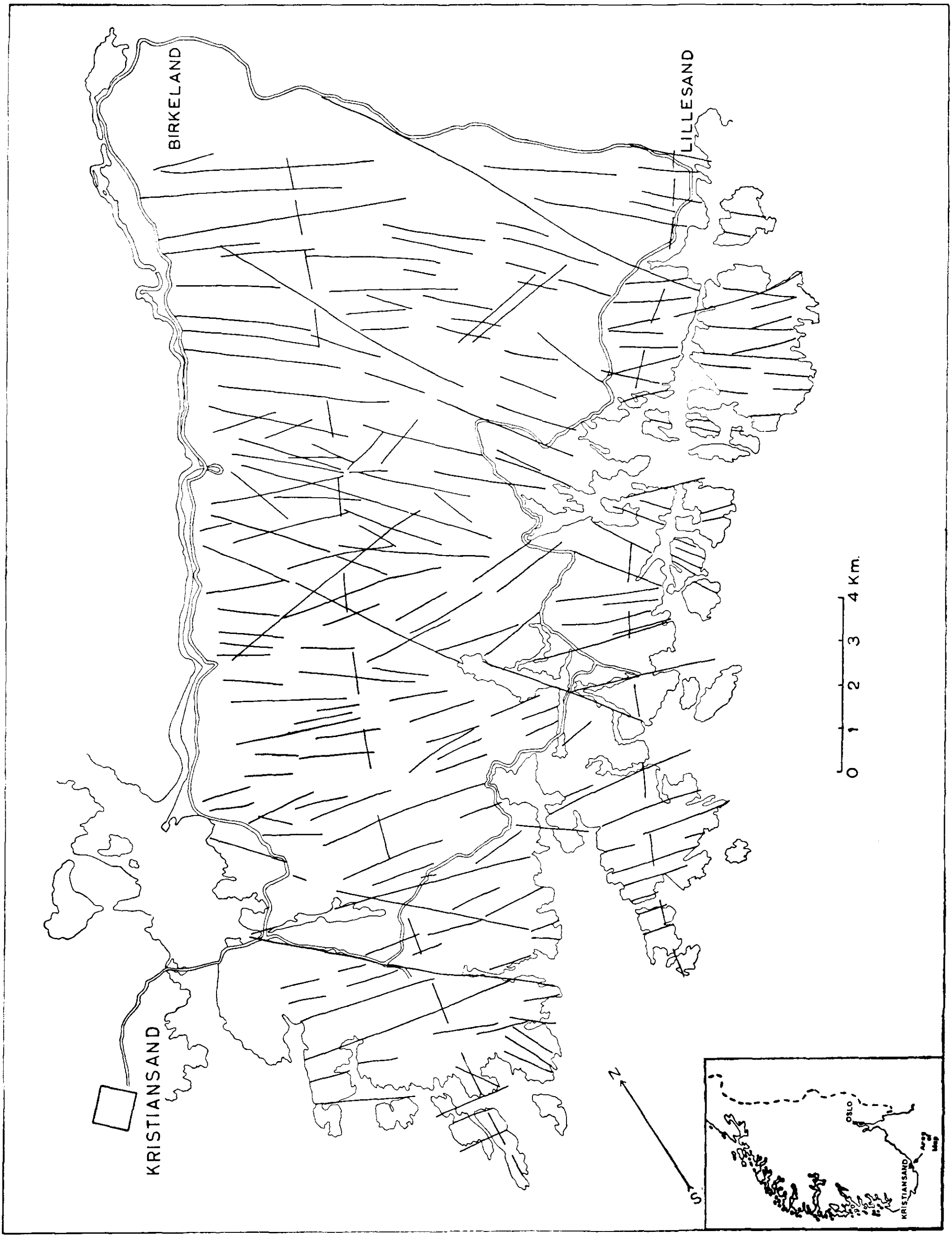

Figure 2. Cross-foliation alignments in the topography of the Randesund area (the two nearly N.—S. dashed lines indicate the general strike of foliation).

Markerte topografiske retninger i Randesund området (de to tilnærmet N.—S. linjer indikerer den typiske foliasjonsretningen).

cation of forces too far off, application directionwise, the general structural trends to be taken up essentially along those trends — this would mean that their positions were controlled by the earlier folding(s) spatially but probably not temporally; 3) the approximately N.50°W. set might be feather joints, or something akin to these, associated with the main fault zone. The first suggested alternative appears unlikely from a dynamic analysis standpoint. The possibility concerning only the approximately perpendicular to foliation set, 2, appears at least a logical though incomplete explanation — especially in light of the fact that the trends appear everywhere to be more nearly perpendicular to the strike than concentrated at any certain azimuth. The feather joint possibility, 3, suggested for the approximately N.50°W. set does not appear likely — this set has expression over an extremely large area, much of Sørland, one which is much larger than would normally be expected as manifestation of feather jointing initiated by the main faulting; further, the alignments appear to have no arcuate divergences dependent upon drag near the fault zone and their orientation actually is not harmonious in these dimensions, so far as the feather joint possibility is concerned, with movements generally considered to have obtained along the zone. Also important to further considerations is the fact that no individual alignment has been recognized to cross the zone of the "Great Friction Breccia".

Miscellaneous Minor Structural Features. — Numerous minor structures and structural-associate features other than the forementioned slickensided surfaces, minor folds, breccia zones, *etc.* occur within the Randesund area. A few of these that are noteworthy are the following. Some slickensided surfaces in the vicinity of the "Great Friction Breccia" are post-pegmatite formation. Chlorite-rich layers within the banded gneiss and the meta-arkose are typically crenulated, sheared, and/or smeared out with orientation of the axial planes of the crenulations or of the shear planes indicative of latest effective movement but not necessarily indicative of major movement. Most "dents de cheval" have their greatest dimensions parallel or subparallel to the foliation of the surrounding rock. Some of the "dents de cheval" (which, by the way, have been found to measure up to 40 cm. in greatest dimension) are so arranged that they define a lineation on foliation planes. Their locations and relationships to the surrounding rocks appear to favor the interpretation that at least many owe their positions to syntectonic dilatency. Boundinage occur locally, as, for example, near Mofia on Route 40 epproximately 2.7 km. S.35°E. of Birkeland. One of the best examples of foliation that is not parallel to relict stratification is near the crate mill on the Kvaase Fjord near Randvig (approximately 4.5 km. S.50°W. of Høvåg). Ptygma occur locally as on the small island (Krågerøen) southwest of Randøy. Highly contorted folds similar to but not true ptygma occur locally as along with drag folds near the abandoned fortifications near the southeastern side of Justøen island, approximately 6 km. S.15°W. of Lillesand. Distortions suggestive of flow of some type occur in many units, for example, in an amphibole-rich foliate within the banded gneiss at the water edge a couple of meters west of the road south of Tømmerstø, about 6.5 km. S.60°E. of Kristiansand.

Perhaps the most important thing about all these "miscellaneous minor structural features" is best exemplified by relationships such as those that can be made on the new side road to Romstøl off from the Randesund—Kvarenes road, approximately 7.5 km. S.50°W. of Høvåg. Here may be seen a mylonitized quartz-feldspar band within the banded gneiss cut by straight quartz veins which have been faulted with the fault "healed" by epidote. Obviously, results of at least five steps in the history of the rock can be observed at this single exposure. I believe that such relationships point up rather graphically that intensive field studies with particular emphasis (or, at least on par with chemical and petrographic emphasis) on physical interrelationships must be undertaken before anything like the complete geologic history — undoubtedly one that is much more complex than even suspected at present — can be synthesized.

Overall Considerations. — As already noted, observations made during my reconnaissance support the interpretation that the Randesund area was faulted downward along the "Great Friction Breccia" zone with respect to the Telemark area which is west of the zone. It is quite apparent that the fault zone is not parallel to but trends more nearly northwardly than the general strike of the foliation. What the dip of the fault zone is within the area is not apparent at observed exposures. W. A. Elders, who is now studying the zone directly northeast of the area interprets evidence there to indicate a moderate southeastwardly dip slightly oblique to that of the rock foliation (personal communication, 1958). J. P. Schaer (personal communication, 1958) has observed similar relationships along large segments of the zone northeast of the area. These observations pretty well establish the fact that the movement is that of a normal fault. This, of course, means that the movements responsible for the faulting were different from those responsible for the folding(s). Whereas the forces responsible for most of the folding may be resolved to compression along axes trending roughly N.65°W., the forces responsible for the sum total of movements along the fault are contrariwise resolvable to extension along axes at about N.75°—80°W.

Sequentially, movements along the "Great Friction Breccia" zone appear to postdate most of the folding movements and the features expressed as alignments appear on the basis of presently known data to fit possibly any temporal position postdating the folding. In this regard it is noteworthy perhaps that similarly resolvable forces so far as general direction is concerned could also account for many of the Caledonian structures of the Oslo Province — possibly indicative of a control of younger movement expressions by older structural trends, possibly suggestive of Caledonian movements having noticeably affected the older rocks.

Economic geology.

The locations of the abandoned mines and prospects indicated on the map (Fig. 2) have been previously indicated on published maps (Foslie, 1925, map; Barth, 1931, p. 142).

The five pegmatite deposits are, listed from north to south, Grovigen, Strømme, Rona, Torsvik, and Søm. Only Strømme, Rona, and Søm were ever worked. Barth (*op. cit.*) considered only Søm to contain more workable feldspar. None of the pegmatite masses within the "pegmatite-rich" areas indicated on the map appear either pure or large enough to be worked economically at present. Possibly at some future date conditions will become such that a central receiving mill for the whole area will make some of the larger masses worth working.

Of the other prospects, only the Kornbrekke nickel deposit, located approximately 9 km. east of Lillesand, was ever in production. According to information in the files of Norges Geologiske Undersøkelse the mine was first worked in the 1870's; in 1873, 318 metric tons of ore that ran 1.5 per cent metallic nickel were mined; in 1915, the shaft was cleared, the ore was found to be disseminated pyrrhotite and chalcopyrite running about .45 per cent nickel, and the mine was pronounced worthless. None of the showings at the indicated prospects or elsewhere appear to warrant further intensive exploration under present economic conditions.

During World War II, the Germans had a few pits dug along the breccia zone of the "Great Friction Breccia" near and south of Bøen and east of the Bøen—Ve road (about 10 km. from Birkeland). These were reportedly to prospect for iron and manganese. At one of these pits there is exposed a little hematite-rich clay (gouge ?) that might be acceptable as raw material for pigment or battleship linoleum but certainly not as iron ore. The amount present appears to be extremely small. It appears that some of the socalled prospects were dug only for use as bunkers.

As mentioned in the section "Marble" some $CaCO_3$-rich rocks near the Bjelland farm were quarried and burned for lime. This was sometime between 1907 and 1915. The burnt lime was used for agricultural purposes. Although many of the soils of the area are certainly lime-deficient, it seems unlikely that these small deposits will be worked for this or other purposes in the future.

The only mineral resources of the area that do presently appear to have assured future use are sand and gravel for road metal, fill, and cement aggregate; various rocks for crushed stone fill and road metal; and, some types of banded gneiss and amphibole-rich foliates for flagging and foundations. The largest and apparently the best so far as diversity-of-use sand and gravel deposits occur along Topdals River, especially north of Ve which is about 10 km. N.45°E. of Kristiansand. Smaller deposits occur sporadically as, for example, west of Tveite which is located about 2.5 km. S.15°E. of Birkeland. Crushed stone for fill and road metal are available almost everywhere and are generally procured from the cuts made in conjunction with the construction that also requires the fill material or, in a few cases, from small roadside pits. Flagging and foundation dimension stones are also generally procurable near where they are needed. Although none of the materials is of such quality that more than local or near-local use will arise, each will serve all presently foreseeable local demands.

On the basis of structural considerations and the facts that sulphide minerals do occur coating joint surfaces in the area and that most cross-foliation alignment features are not observable in outcrop and thus not amenable to visual prospecting methods I believe future mineral exploration within the area should be directed mainly towards geophysical investigation of these zones.

Epilogue.

I believe that the main thing this report points up is that the Randesund area needs many detailed field studies before anything like a complete picture of its geologic history can be presented. I sincerely regret that time has been so short that it was impossible for me to examine most of the many extremely interesting geologic features in more than a cursory fashion. I hope that this report will serve to promote interest and further work in the area.

Sammendrag.

Geologiske iakttagelser i Randesund-området.

Randesund-området, et felt på ca. 400 km^2, ligger mellom Lillesand og Kristiansand, dels i Aust-Agder, dels i Vest-Agder fylke. Innen området er det utført petrografisk-tektoniske undersøkelser for Norges Geologiske Undersøkelse høsten 1958 (28 dager).

Det er ikke gjort forsøk på å revidere bergartsgrensene slik de er tegnet på dr. A. Bugge's kart (Bugge 1939). Det vesentlig nye er fremleggelse av en tektonisk tolkning av feltet og en revisjon av ideene vedrørende dannelsen av de bergartstyper som forekommer.

Båndgneis av forskjellige typer er den mest alminnelige bergart. Noe mindre utbredelse har meta-arkose, amfibolrike gneiser og meta-gråvakke. Forekommende i mindre felter finnes kalkstein, pegmatitt, amfibolitt og doleritt. Alle de nevnte bergartstyper, unntatt de tre siste, synes å være av suprakrustal opprinnelse. Bare doleritt og noen pegmatitter er umetamorfe.

Den «store rivningsbreksje i Syd-Norge» sees innen den vestligste del av feltet. Resultatet av bevegelsen langs denne forkastningssone synes å ha vært av den «normale» type med en senkning av Randesund-området i forhold til det vestenforliggende «Telemark-området».

Bergartene er foldet og lokalt oppsprukket og forkastet. Foliasjonen synes vesentlig å falle sammen med den opprinnelige stratifikasjon. Strøket er gjennomgående nordøstlig og fallet er overalt mot nordvest unntatt innen den østligste del av området ($^1/_5$ av Randesund-området) hvor det er sydøstlig fall. Selv om bare en hovedfold, en antiklinal i østre del av feltet, er så vel utviklet at den kommer klart frem, er det grunner som tilsier at det finnes mange flere, antagelig isoklinale folder. Markerte topografiske retninger, hvorav de fleste løper omtrent loddrett på strøket, mens andre har retningen N.50W., antas å være diktert av sprekker og/eller tverrfolder. På grunnlag av de sparsomme opplysninger som foreligger kan det bare antydes at hovedfasen av foldingen er eldre enn de betydelige bevegelsene i den store rivningsbreksjen. Andre tektoniske trekk så som oppsprekking og tverrfolding har det ikke vært mulig å innpasse i feltets geologiske historie.

De mineral- og malmforekomster som er sett innen feltet, likesom forekomster av sand og praktisk anvendbare bergarter etc., har bare lokal økonomisk betydning.

Det var å håpe at den fremlagte rapport fra et rent oversiktsmessig feltarbeide kan øke interessen for geologien innen denne del av Sørlandet. Nettopp med dette i tankene er det gitt antydninger om de linjer som fremtidige undersøkelser med fordel kan følge, idet man begynner med bergartene innen Randesund-feltet. Forholdene ligger her vel tilrette for å komme nærmere løsningen av betydningsfulle problemer av almen interesse, så som dannelsen av granittiske bergarter og pegmatitter, av amfibolittiske bergarter og «båndgneiser».

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