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Characterization of the morphology, basement rock and tectonics in Sweden

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ABSTRACT

This report is a compilation of the knowledge of the morphology, the bedrock geology and the tectonics of Sweden. The compilation is mainly based on published articles and maps. The result is presented on seven maps.

Sweden is subdivided into three terrain types, South-East Sweden Terrain, Norrland Terrain and Caledonian Terrain.

South-East Sweden Terrain is dominated by the sub-Cambrian peneplain, the elevated and fractured sub-Cambrian peneplain and Tertiary denudation surfaces. The dominating landforms are plains and fissure-valleys, with a relative relief of 20-50 meters.

The Norrland terrain is characterized by an undulating hilly landscape with a relative relief of more than 100 meters. The most northern part is dominated by monadnock plains.

The Caledonian Terrain has not been included in the study.

Sweden is a part of the Baltic Shield, a Precambrian craton area.

The bedrock is predominated by Precambrian hard rocks.The geology is subdivided into three large domains, mainly based on the geological deformation history. The oldest rocks of Archaean age are found in northern Sweden, where they are related to the Archaean domain, the nucleus of the Baltic Shield.

The Svecofennian domain covers most of Sweden. The domain is subdivided into four subdomains the North, Central and South subprovinces and the Transscandinavian granite-porphyry belt. The latter is thought to represent the later stages of the Svecofennian orogeny.

The Southwest Scandinavian domain represents rocks found on the southwest part of the country.The boundary between the Southwest Scandinavian Domain and the Transscandinavian granite-porhyry belt is an extensive tectonic zone, the Protogine zone.

The dominating rocks within the different domains are granites, gneissic granites and gneisses. Supracrustal rocks of both sedimentary and volcanic origin are locally observed. In some areas they predominate.

The tectonic structures have been evaluated from geological and lineament maps. The latter based on Landsat III images and the Relief map of Sweden.

A new lineament map based on the Relief map is presented. This map shows an acceptable correlation with the lineaments based on Landsat images, when large tectonic elements, >50km, are compared in southern Sweden. The correlation is worse for north Sweden.

The paper presents a new interpretation of lineaments regarding location, direction and length of large lineaments, a regional density map of lineaments and the regional distribution of orientations of lineaments.

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SUMMARY

The objective of this report is a compilation and characterization of the morphology, the bedrock geology and the tectonics in Sweden. The state of the art report is mainly based on published articles and maps.

The morphology is presented in one map including the subdivision of the terrain types, peneplains and denudation surfaces, absolute and relative relief and description of landforms.

Sweden can be subdivided into three main terrain types; the Caledonian, the Norrland and the South-East Sweden Terrains. Six different peneplains and denudations surfaces are observed. The sub-Cambrian peneplain is the most important, which covers large areas of southern Sweden. The Norrland Terrain is dominated by a hilly landscape and monadnock plains. The relative relief and the landforms are described with ten classes.

The bedrock geology has been compiled from the latest available maps in scales of 1:200 000 to 1:500 000. The original maps were reduced photographicly to the map scale of 1:2 000 000. The map was compiled directly on the photographs. Most original geological maps have been produced during the last 5-6 years, except for north Sweden, where the maps are older.
The result of the compilation is a new geologic map in the scale of 1:2 000 000, where the different rock types have been reduced to only eigth.
The main purpose of the study has been to outline the area of a specific rock and describe this rock independent of its age and evolution. Therefore granites of different ages have the same symbole on the map.

The dominating rocks are granites, gneissic granites and gneisses. Supracrustal rocks of both sedimentary and volcanic origin occur locally and they may be dominating in some regions.

The compilation of the tectonic structures is based on geological maps, where the major tectonic zones are known, and on lineament maps based on Landsat III images and the Relief map of Sweden.

A new lineament map is presented based on the Relief map, which is illuminated from NW and W. A correlation test made between these lineaments and mapped geolocial minor tectonic structures are in good agreement

Major lineaments ()50 km) based on the Landsat III images have been correlated with lineaments from the Relief map. There is an acceptable agreement for these features in southern Sweden, while the correlation is worse for northern Sweden.
A lineament density map based on Landsat III images gives a regional distribution of the densities. A regional distribution is also presented for the dominating orientations of the lineaments.

It is asserted that the lineament maps based on the Relief map mainly reflects the large tectonic structures in the bedrock.

1. INTRODUCTION

1.1 THE BEDROCK

The basement rock of Sweden is a part of the Baltic Shield, a craton with a nucleus of Archaean age (Figure 1). The Baltic Shield incorporates the countries of Sweden, Norway, Finland parts of Sovjet Union including the Kola peninsula. The rocks within the Baltic Shield are mainly of Precambrian age and are covered by Paleozoic and younger sedimentary rocks towards southwest, south and southeast.

The Precambrian basement rocks within Sweden have a western boundary towards the Caledonides, which comprise of thrusted nappes of Paleozoic and Precambrian age. The border zone in south consists of a fault, the Danish-Polish Trough, with mainly Mesozoic and Kenozoic rocks of large thicknesses. Similar sedimentary rocks cover the Precambrian towards southest.

The Precambrian rocks at the bottom of the Bottnian Sea is mainly covered by Jotnian and younger Precambrian sedimentary rocks, some Cambrian and Cretaceous sediments.

1.1.2 Age of Precambrian rocks

The Baltic Shield demonstrates a geochronological zonation (Gaal and Gorbatschev 1987) with the oldest rocks, the nucleus, in northeast and the youngest in southwest.This zonation can be correlated to three major orogenic periods, when continental crust has beed formed and added to the nucleus.These orogenic events cover the time intervals 2.9-2.6 Ga (Lopian orogeny), 2.0-1.75 Ga (Svecofennian orogeny) and 1.75-1.5 Ga (Gothian orogeny).

The zonation of the Baltic Shield in Sweden subdivides the region into three domains related to the orogens i.e. the Archaean domain, the Svecofennian domain and the Southwest Scandinavian domain. The Transscandinavian granite-porphyry belt represents rocks belonging to the later stages of the Svecofennian orogeny.

The Precambrian rocks within the swedish part of the Baltic Shield are dominated by rocks which are younger then 2.5 Ga. Archaean rocks, older then 2.5 Ga, are only found in the nothern part of region related to the Archaean domain of northern Finland and the Kola peninsula.

1.1.3 Subdivision of the Precambrian rocks in Sweden

The rocks are subdivided into regions or domains mainly based on the orogenic zonation, large tectonic structures and/or petrological and metamorphic relations.

According to Magnusson et al (1962) and Gaal and Gorbatschev (1987) the following subdivision can be made (Figure 1):

1. Archaean Domain
2a. Svecofennian Domain
2b. Transscandinavian granite-porphyry belt
3. Southwest Scandinavian Domain
4. Caledonides
5. Late Proterozoic and Phanerozoic platform cover

1.2 THE MAIN TECTONIC STRUCTURES

A number of large tectonic structures have been recognized in Sweden.
The two largest zones are the Danish-Polish Trough and the Protogine zone (Figure 1).

The former, also named the Törnquist Line, forms the southern boundary of the Baltic Shield. The zone is a part of the intra-plate plate tectonic pattern of Europe, with a complex tectonic history.The zone is composed of a number of mainly subparallel faults oriented in NW-SE and accampanied by dolerite dykes in the same direction. The tectonic evolution indicates both horisontal and vertical movements of which the latter is several thousend meters.The development of this tectonic zone can be traced to early Paleozoic time.

The Protogine zone forms the border between the Southwest Scandinavian Domain and the Transsvecofennian granite-porphyry belt.The zone is characterized by foliated and mylonitized rocks. The tectonic character of this zone is however not understood in detail.Vertical movements of the order of 1000m-1500m has been reported along lake Vättern. The zone has developed during several tectonic phases of faulting during Precambrian time with final activation around 0.9Ga. It is accompanied by instrusions of granites and mafic dykes.

Three main faults are recognized within the Southwest Svecofennian Domain the Dalsland fault, Göta älv zone and the Mylonite zone. These faults subdivide the domain into three segments.

The North Svecofennian Domain (NSD) has a major tectonic zone,the Skellefte zone, which has been interpreted as a Proterozoic subduction zone by Loberg (1987), whilest Gaal and Gorbatschev (1987) have described the zone as a strike slip fault.

1.3 THE QUATERNARY EVOLUTION

Four ice ages have been recognized during the Quaternary period.The latest ice age (Weichsel) started 75000-100 000 years ago with the growth of the glaciers in the Caledonides. The ice continued to grew until a thick sheet of ice covered the Baltic Shield and adjacent areas. The ice cover is thought to have been 3000 m in thickness and it had its growing center located in the northern part of the Caledonides.

The ice movement from this center was to southeast in northern Sweden and towards south in the southern parts. The movement along the West coast of Sweden was towards southwest, while it was southeastwards on the East coast south of Stockholm.

The melting of the ice started in southern Sweden about 15000 years ago. The regression of the ice front took almost the same directions as during the growing period.

Most of the soil cover was developed during the latest ice age. The thickness of the cover is 5-15 meter with a maximum value of 194 meters.

The dominating soil is drift deposites, moraine, with varying thicknesses and compositions .The drift is normally deposited directly on the bedrock.

Glaciofluvial deposites are dominated by eskers and deltas.They normally are developed as more or less continuous features, which are strictly bound to the valleys or lower parts in the terrain. Glaciofluvial deposites and landforms are spares or missing in terrains of low relative relief.

The growing and regression of the ice is the most important factor for the development and creation of the landforms.

2. MORPHOLOGIC DESCRIPTION OF SWEDEN

The characterization of the morphology of Sweden is made by presenting the different peneplains, terrain types , landforms, absolute and relative relief.

The peneplains and to some extent also the relative relief are mainly developed by active actions of tectonic movements and exogenous processes as weathering and transport processes. Most of the transport from areas of high altertude to the sea, is made by rivers. If the masstransport goes on for a very long time without disturbances of tectonic movements the result will be a lowered or flat relief. A flat erosion surface or a peneplain is created. A geomorphological plain is defind as an area with a slope less then 1 degree and a relative relief less then 20 meters.

The relative relief, the terrain and land forms, are manily the result of the moving ice.

2.1 WORKING METHOD

The distribution of peneplains or denudation surfaces, the landforms and the relative relief for Sweden are compiled to one map Figure 2.

The compilation is mainly based on the following material:

Atlas över Sverige nr 3-4 " Relative relief of land surface, 1963
Atlas över Sverige nr 1-2 " Land relief", 1957
Atlas över Sverige nr 5-6 " Gravity, Stratigraphy and Tectonics, 1970
Elvhage and Lidmar-Bergström, 1987
Relief map of Sweden, Lantmäteriverket, 1987.

Sweden can be subdivided into three terrain types namely South-East Sweden Terrain, Norrland Terrain and the Caledonien Terrain (Figure 2) .Different peneplains or denudation surfaces can be distinguished. A total number of 6 such plains is presented. Of these the sub-Cambrian peneplain is the most important. Different types of morphology, landforms, have developed whithin each peneplain area.These different types are described in general together with the absolute and relative relief. It should be noted that the landforms may not coincide with the border of the peneplains

The Caledonian Terrain is not included in the study.

2.2 THE SOUTH-EAST SWEDEN TERRAIN

The South-East Sweden Terrain (SEST) covers the southern part of Sweden and a strip along the East coast. The dominating peneplain whithin SEST is the sub-Cambrian peneplain. The Sub-Mezosoic denudation surface and the Tertiary denudation surface have large extents in the south-central parts.

The sub-Cambrian peneplain is the oldest and is distinguished from the Norrland terrain and the uneven relief of southern Sweden. The peneplain is subdivided into two parts manily based on the relative relief namely the low lying areas (1) and the elevated and fractured parts (2). Peneplain of type 1 covers the total length of the East coast and the region around lake Vänern. Area type 2 covers the region between the East coast and lake Vänern and a smaller region west of lake Vänern.

A weathering zone on the sub-Cambrian surface is often found in areas outside the Cambrian sedimentary cover. The maximum depth of this zone is 5 m.

2.2.1. The sub-Cambrian peneplain

The sub-Cambrian peneplain along the east coast has a morphology comprising of plains with relativ heights below 20m and a fissure-valley landscape. The latter morphological type is particularly common southwest and south of Stockholm .Here the fractures and other structures are clearly observed but the valleys are not deep. The relative relief is between 20-50 m.

The northern strip of sub-Cambrian peneplain, north of Stockholm, comprises of greater relative relief and an increasing gradient. These areas normally have hilly land with relative heights of 20-50m along the coast line and undulating hilly landscape with relative heights of 50-100m towards the main land.

The region 1 type, surrounding lake Vänern, is dominated by low relative relief below 20m. The landscape becomes more hilly towards west and south with undulating hilly landforms with relative heights of up to 100m.

The table mountains can be correlated with remnants of the Paleozoic rocks covered by sills of dolerite.

The peneplain type nr 2 ,elevated and fractured sub-Cambrian peneplain, is dominated by three classes of landforms. East and west of the southern part of lake Vättern the landscape is described as undulating hilly land with relative heigths of 50-100m. The area south and south east of lake Vättern is named the Highlands of Småland. Locally the relative heights increase to more then 100m and the landscape changes to hilly-mountain type. This type of landscape surrounds lake Vättern in the southern parts and is caused by faults running parallel to the lake.
The relative height decreases towards west and northwest and a fissure-valley landscape is formed.

The region north of lake Vättern is a fissure-valley landscape with low relief.This landscape changes towards north into an undulating hilly type with increasing relative heights.

2.2.2 The sub-Mesozoic denudation surface

The sub-Mesozoic denudation surface is denoted number 3 type of plains, which covers the southern and southwestern part of Sweden. These surfaces emerge from covers of Jurassic and Cretaceous rocks. A deeply kaolinization , up to 50m, is locally observed on these surfaces. The landscape is characterized by an uneven topography with boulders.

A low relative relief is dominating in the southern parts. However, local areas with greater relative heigths, more then 100m, have developed due to the tectonic evolution of horsts and grabens.

One of the best examples of the fissure-valley landscape is demonstrated in the eastern part of the region in the County of Blekinge.

The West coast of Sweden is dominated by a fissure-valley landscape. Towards south the relief increases to heights of 125-150m. Approximatly 40 percent of the area has a

relative relief of more then 100m. The landscape locally changes to an undulating hilly/ hilly mountain terrain.

2.2.3 The Tertiary denudation surface

The Tertiary denudation surface, type nr 4, covers a large region in southern Sweden. The south part of the area, named the South Småland peneplain, forms an extensive plain with relative relief less then 25m and with only a few residual hills.
This plain can be traced from the East coast of Sweden (southern part of region nr 1) to the southern parts of the West coast (south and southwestern parts of region nr 3)

The plain has an altitude of 125-150m above sea level, but raises towards north and reaches 200m above sea level at the southern part of lake Vättern.

The landforms change from the southern parts of the region towards north from a plain with relative relief below 20m through monadnock plain to an undulating hilly landscape with relative heights between 20-50m.

2.3. THE NORRLAND TERRAIN

The region northwest and north of the South East Sweden Terrain covers 2/3 of the area of Sweden. This area is dominated by an undulating hilly/mountain landscape with a relative relief of more then 100m (100-200m, maximum 400m).

However, the relative heights along the border towards SEST varies between 20-50m with a fissure-valley landscape development or 50-100m with an undulating hilly landscape.

The central and the northern parts are encountered as monadnock plains. A pre-monutain terrain is observed towards the Caledonian Terrain.
The Norrland terrain has been characterized to include more large-scale landforms than in southern Sweden and there is no good descriptive term for that type of landscape. According to Rudberg (1970) the terrain " is a rolling land with densly spaced ridges and hills, sections of valleys or irregular depressions, often filled with lakes". Plains of any considerable size are rare. Rudberg has identified 13 peneplains and/or valley generations.

3. GEOLOGIC DESCRIPTION OF SWEDEN

3.1 WORKING METHOD

The geological map of Sweden is presented in Figure 3. This map is based on the latest available geological maps published by the Swedish Geological Survey (SGU). The map has a scale of 1: 2 000 000, which make it not possible to present details of the geology.

The Caledonien mountain is not considered in the study.

The following maps are the base of the compilation:

Blekinge län, Ah 4, 1983; Uppsala län, Ah 5, 1984; Stockholms län, Ah 6, 1985; Södermanlands län, Ah 7, 1984; Hallands län, Ah 8, 1986; Kronobergs län, Ah 10, 1986; Älvsborgs län, Ah 13, 1986; Skåne, Ah 15, 1988; Sveriges Berggrund, Ba 16, 1958, Västernorrlands län, Ba 31, 1987; Oskarshamn, Ba 34, 1985; Jönköping, Ba 39,

1985; Borås, Ba 41, 1987; Västerbottens län, Ca 37, 1955; Kopparbergs län, Ca 40, 1964; Norrbotten, Ca 41, 1957; Jämtlands län, Ca 53, 1984; Gävleborgs län, SIND, 1980; Värmlands län, SIND, 1982; Västmanlands län, SIND, 1981; Berggrundskarta över Örebro län, Planeringskarta, 1984.

The geology as presented in Figure 3 is a simplified geological map, where the number of different rock types has been reduced to only eight.

All rocks younger then Cambrium are presented with one symbol.

The plutonic rocks, irrespective of age, have been divided into two groups, those ranging from granite to granodiorite,and those of mainly basic compositions, including sills and bodies of basalt/dolerite.These igneous rocks are normally non-foliated. However, local foliation, especially at the margins of the bodies, is observed.

Foliated igneous rocks, irrespective of age, are distinguished as gneisses ranging in composition from granite to granodiorite.

Gneisses of sedimentary and volcanic origin are normally fine-grained and dens, with a marked foliation.The dominating type of the two is choozen to be represented on the map in areas where both types of gneisses are observed intercalated.

Metasedimentary and metavolcanic rocks have more or less well visible and preserved original texturs. The sedimentary rocks often have a foliation, which can be described as a layering, whilst the volcanic rocks normally are non-foliated and dens.The latter rocks cover larger areas compared to the sedimentary rocks.

Specific features as dolerite dykes, migmatitization and important rock groups are denoted with capitals.

3.2 THE ARCHAEAN DOMAIN

The Archaean rocks only covers a small part in north Sweden (Figure 1). The rocks are suggested to belong to the Lopian orogeny (2.9-2.6 Ga). Metavolcanic and metasedimentary rocks of the Lopien Supergroup occur along the border to Finland. These rocks have been reworked during the Svecofennian orogeny and are today represented as migmatites and gneisses.

3.3 THE SVECOFENNIAN DOMAIN

The Svecofennian Domain can be subdivided into three subdomains based on the differences in paleoenvironment of the supracrustal rocks, namely the North , the Central and the South Svecofennian subprovinces. The North and South subprovinces have a dominating terrestrial supracrustal volcanic facies, whilest the Central subprovince mainly has a marine facies and composed of metamorphosed greywackes and pelitic rocks.These rocks developed during the Svecofennian orogeny (2.0–1.75 Ga).

3.3.1 The South Svecofennian subprovince

The rocks within the South subprovince form a very complex pattern between supracrustal and plutonic rocks.The dominating rock is comprised of different types of granitic gneisses and granitoids, especially within the area north of an east-west line through Stockholm.

The metavolcanic gneisses are mainly gathered within a band, which forms a slight U-shape open towards east. The southern leg of the U is subparallel to the boarder between the Transsvecofennian belt and Svecofennian Domain. The northern leg passes though the subprovince towards northest. The gneissic granites are normally only observed as isolated bodies within the metavolcanic belt. Metasedimentary rocks are the dominating supracrsustal rock south of the east-west line through Stockholm.

The metavolcanic gneisses, the Leptite formation, comprise manily of acid volcanic rocks. Basic volcanics are observed locally. The rocks are dense and normally have a very marked foliation.
Intercalations of limestone, black schist and greywackes are locally observed.

The metasedimentary rocks in the Stockholm area are normally mainly composed of sedimentary gneisses of metamorphosed slate, sandy greywacke and limestone. These rocks form the the Mälar Group (MG).

Metasedimenatry rocks mainly composed of quartzite and minor portions of greywackes and slates, Västervik Group (V V), are found in the southern part of the domain.Original primary textures are observed in these sediments. The rocks are metamorphosed towards the contacts to the surrounding granites with local development of migmatites.

The metasediments in the northern part of the subprovince are dominated by greywackes of Härnö Super group (HS). Intercalations of basic volcanics occur in the lower parts of the formation while quartzites and arkoses are found in the upper part. The thickness of these supracrustal rocks are in the order of 3000-6000m.

The gneissic granites which cover more then half of the domain consist of a suit of gneisses of plutonic origin. These rocks are more or less foliated and comprise of gabbroe, diorite, tonalite, granodiorite and granite of calc-alkaline I-type. These suit has been named the" urgranit". The largest area is covered by Uppsala and Vänge granites.

Both the supracrustal and the gneissic granites have been deformed and regionally metamorphosed, large areas have been migmatitized and melted.These melts have intruded both the supracrustal and gneissic granitic rocks to form more or less non-foliated diapiric granites of Stockholm and Fellingsbro type. . These granites are not differentiated into a plutonic suit. They normally are medium- to fine-grained, even-grained but sometimes porphyritic in texture. Large quantities of pegmatite dykes and bodies form the late stages of the granitic intrusions.

3.3.1.1 The County of Blekinge

An area of Svecofennian rocks belonging to the south province is distinguished south of the Transsvecofennian granite-porphyry belt in southern Sweden. This area is mainly found within the County of Blekinge.

The dominating rocks are gneissic granites and granites (Karlshamn granite) while minor parts are covered by the Västanå supracrustal group (VG) and sedimentary gneisses.

The Västanå Group comprises of acid volcanics, mica schists, mica-quartzites, quartsitic conglomerate and amphibolite.

The sedimentary gneisses are even-grained, medium- to fine-grained with a marked gneissic foliation which is folded.

The gneissic granites are thought to be of similar origin as those described from the Stockholm area. Basic types are in minority.

The area is intruded by coarse normally porphyritic granits of Karlshamn type. These granites are homogeneous and non-foliated. Acid dykes and pegmatite dykes are associated with these granites.

Dolerite dykes intersect the bedrock normally with an orientation in NNE-SSW.

The Precambriam rocks are overlain by Phanerozoic rocks in eastern and southwestern parts of the area.

3.3.2 The Central Svecofennian subprovince

The Central Svecofennian subprovince is bordered towards south of the South subprovince and to the north of the North subprovince. The northern border is approximatly eqvivalent with the Skellefte tectonic zone.
The Caledonides make the western limit.

The geology is dominated by sedimentary supracrustal rocks and granites.
The supracrustal rocks are mainly found along the eastern margin of the province and comprise of metamorphosed greywackes and slates of the Härnö Super group. Sandy types as well as basic volcanics are locally identified.The thickness of the formation is probably in the order of 10000m. Sedimentary structures are found in the low metamorphosed sequences, but normally the sediments can be denoted as mica-schists or sedimentary gneisses which are veined or banded with a predominating foliation. Large areas are migmatitized.

Only smaller areas of gneissic granites of similar types as described from the South subprovince have been identified. These granites are manily found in the southern part of the province and only as smaller bodies in the central and western parts.
The suit comprises of gabbroe, diorite, tonalite, granodiorite and granite. Granite and tonalite are the predominating types in the southern part of the province , whilst granodiorites often with augens and pegmatite dykes are observed in the central and north parts. Gabbroe is rare. The rocks normally have a gneissic foliation but more or less homogeneous areas are identified.
These granites are of magmatic origin.

The western and northwestern parts of the region are covered by large areas of homogeneous non-foliated granites of Revsund and Härnö types. The latter granite is associated with the migmatitization of the area, during which large quantities of pegmatites were imposed. These granites normally are non-foliated and can be correlated with the Stockholm granites. The rock is especially outcropping as smaller bodies within the supracrustal rocks.

The Revsund granite is a suit of plutonic rocks ranging from diorite, granodiorite, granite to Rapakivi granite. Gabbroe and diorite are associated with the Rapakivi granite. The Revsund granite suit normally is a homogeneous ,grey medium- to fine-grained rock. Locally it becomes coarse or porphyritic.

The southern and the southeastern part of the domain have large areas of basalt intruded as sills or dykes. These form the youngest rock of the area.

3.3.3 The North Svecofennian subprovince

The North Svecofennian subprovince covers the area of the northern part of Sweden, from the Skellefte teconic zone in south to the Archeaen Domain in north. The Caledonides form the western boundary.

The region shows a similar rather complex distribution of the geology as found in the South Svecofennian domain.

Granitic and gneissic granitic rocks are predominating. Supracrustal rocks of sedimentary origin cover large areas in the southeast part of the region whilst volcanic rocks mainly are present along the southern border and as smaller irregular bodies spread elsewhere.

Three main lithostratigraphic groups are distinguished among the suprcrustal rocks in the south part of the subdomain. The oldest group is predominated of acid volcanics (Skellefte volcanics) with intercalations of basic volcanics and greywackes. The second group comprises of metasediments (schist, phyllites and metagreywackes). The youngest group contains the Arvidsjaur volcanics, dominated by acid volcanics with local basic volcanic affinities. The first two groups are thougth to be of marine deposites whilst the youngest is terrestrial.

The sedimentary rocks in the north and the northest part of the subprovince comprise of basic volcanics intercalated with limestone, phyllite, schist, quartzite and conglomerate. These sediments are normally well preserved.

The gneissic granites , the Haparanda series, which form a suit ranging from gabbroe to granite, can be correlated with the gneissic granites in the South Svecofennian subprovince. These rocks are normally foliated.

The supracustal rocks and the gneissic granites have in many areas been migmatitized.

Large areas are covered by non-foliated granites belonging to the Lina granite group. The group contains gabbroe, syenite, granite and pegmatite.

3.4 THE TRANSSCANDINAVIAN GRANITE-PORPHYRY BELT

The Transscandinavian granite-porphyry belt is bordered by the Protogine zone to the west and the Svecofennian Domain towards northeast, east and south (Figure 1). The domain continues northwards structurally below the Caledonides. Cambrian sediments cover the basement towards southeast.

It is thougth that the rocks belonging to the Transscandinavien granite-porphyry belt is closly related to the later stages of the Svecofennian orogeny (1500 Ga).

The oldest rocks within the belt are remnants of rocks belonging to the Svecofennian orogeny. These rocks are mainly gathered within an area oriented in WNW-ESE and located southeast of lake Vättern.

This area is dominated by gneissic granites of varying compositions as well as basic plutonic rocks. Supracrustal rocks of the Vetlanda Super group (V) are outcropping in the northwest part of the gneissic granitic complex. The supracrustal rocks comprise of sediments and volcanic rocks. The latter mainly basic in composition. Sandstone and conglomerate are intercalated with slate. These rocks have a well marked foliation.

The Transscandinavian granite-porphyry belt is completely dominated by granites of the Småland-Värmland suit and related volcanic rocks mainly of acid to intermediate compositions.The latter are mainly found in the north and south parts of the belt.

Sedimentary and volcanic rocks and associated intrusive granites of Jotnien (J) and Sub-Jotnien age cover large areas in the north part, whilest a smaller area of sedimentary rocks and dolerite sills of Jotnien age, belonging to the Almesåkra Group (AG), is found southeast of lake Vättern.

Basic dykes and sills of different age are observed within the whole belt.

The youngest rocks are of Paleozoic age.They build up a faulted ring structure forming lake Siljan and a down faulted triangle east of lake Vättern.

The Småland-Värmland granites are a differentiated suit of rocks ranging in composition from gabbroe to grey and red granites. The rocks are medium-grained and non-foliated. A marked foliation is developed towards the Protogine zone.

The volcanic rocks, the Småland porphyries, are closly related to the granites. They are dominated by quartz porphyry but intermediate and porphyritic types are observed. The rock is red, red-brown or brown in colour, dens and normally non-foliated. Volcanic textures may locally still be preserved.

The northern part of the domain is covered by rocks of Jotnien and Sub-Jotnien age. The largest area consists of sandstone and conglomerate of Jotnien age (J). The thickness of the sedimentary rocks is more then 800m in the southern part but thins out towards north. The sandstone beds are intercalated with dolerite sills and dykes of different age and petrographic character.The dykes also intrude in the surrounding rocks

The volcanic rocks of Sub-Jotnien age , the Dala porphyry (D P), comprises of a varying suit of porphyry and porphyritic rocks intercalated with beds of sandstones.

A suit of intrusive plutonic rocks , gabbroe to granite and Rapakivi granite, are closly related to the volcanic Dala porphyries. This suit is younger then the volcanic rocks and cover the granitic area around the Dala porphyry.The rocks are normally coarse to medium-grained and non-foliated.

The Almesåkra Group (AG), located in the southern central part of the belt comprises of light coloured quartzite, sandstone, arkose and conglomerate. The sediments are intruded by dolerite sills and dykes. The dykes are oriented in NNE-SSW.

The dolerite dykes are normally oriented in NNE-SSW in the southen part of the belt and NNW-SSE in the north part.

3.5 THE SOUTHWEST SCANDINAVIAN DOMAIN

The Southwest Scandinavian Domain has its eastern limit marked by the Protogine zone (Figure 1). The main structures within the domain are the Mylonite zone, the Göta älv zone and the Dalsland fault.

The area between the Protogine and the Mylonite zones has been named the Eastern gneissic segment and is dominated by grey and red gneisses. The Western gneissic segment, between the Göta älv zone, and the Mylonite zone comprises of gneisses and supracrustal rocks of the Åmål(Å) and Dal Groups (DG).

The Stora-Le Marstrand (SL-M) supracrustal rocks and Bohus granite dominate the area west of the Dalsland fault.

The Eastern gneissic segment comprises of complex granitic gneisses. The polymetamorphic and polydeformed area make it difficult to distinct older and younger components of the rock. A petrological zonation is described, where granodioritic gneisses are dominating east of the Mylonite zone while granitic gneisses predominate the area west of the Protogine zone. Smaller remnants of gneissic supracrustal rocks are locally intergrated as well as granitic and pegmatite bodies and dykes .A larger area of granitic composition with more or less well preserved magmatic textures occurs in the sourthern part of the segment, where also some metabasites of amphibolite character are observed.

Hyperite dykes and sills are common within the granitic gneisses.

The youngest rocks in this segment are of Paleozoic age. They are covered by basaltic sills.

The Western gneissic segment can be subdivided into an eastern part dominated by red and grey gneisses and a central and western part covered by the Åmål and Dal Group supracrustal rocks including red and grey gneisses.
The gneisses are of similar types as described from the Eastern gneiss segment and are thought to be of magmatic origin.

The Åmål Group comprises of quartzites, mica rich gneisses and volcanic rocks.
The supracrustal rocks are preserved as remnants completely surrounded by granitic bodies and gneisses.Some show well preserved original textures others are strongly foliated.

The Dal Group comprises of conglomerate, quartzite, slate and greywacke. The thickness of the group is in the order of 1500-2000 m.

Supracrustal rock of the Stora Le -Marstrands formation (SL-M) and the Bohus granite covers the area west of the Dalsland fault. The supracrustal rocks are comprised of greywackes, clay sediments and intermediate volcanic rocks with a metamorphic grade varying between schist and migmatite.

A two-mica gneiss is very common in the southern part of the segment in the Gothenburg area. The rock is intercalated with quartzites. Augen gneisses occur locally.

The gneisses are intruded by dykes of amphibolitic compositions and a suit of basic igneous rocks.

The Bohus granite, 0.9 Ga in age, is structurally homogeneous but varies in colour and texture. The granite has inclusions of gneisses from the Stora Le-Marstrand formation. Large quantities of pegmatite dykes related to the granite have intruded the surrounding rocks.

The youngest rocks within this segment is the Koster dolerite dykes and pegmatite dykes. The latter is related to the intrusion of the Bohus granite.

The geologcial evolution of the Southwest Scandinavien domain is not fully understood.It is thought that the rocks within this subdomain developed and/or were reworked during the Gothian orogeny (1.75–1.5 Ga).

4 THE TECTONIC STRUCTURES OF SWEDEN

Tectonic structures are identified directly or indirectly. The direct identification is made by observation in the field during geological mapping.
A tectonic map covering whole Sweden based on modern geological mapping showing in detail the geological structures of different ranges has not been published. The major tectonic pattern is well known for the southern parts of the country.These structures have been compiled on Figure 4.

A morphotectonic study is an indirect method to analyse the landforms of regional or tectonic significance. The topography is the primary criterion and the basis for the interpretation of the geologic structures. The study is performed on remotely sensed images or photographs.

Airial photographs are the appropriate system for direct mapping of macroscopic-scaled structures as faults, folds,fractures etc while images from satellites can be used for interpretation of the megascopic scaled tectonic features as fold belts, basins, rift valleys etc.

A lineament map of Sweden based on Landsat III images in scale 1: 1 000 000 is available for study of the megascopic scaled structures.

The "Relief map of Sweden", based on topographic maps at a scale of 1:50 000 has been used, for the interpretation of the "smaller" structures, faults larger fracture zones etc

The Lineament map is based on Landsat images at a scale of 1: 1 000 000. Straight lines exceeding 10 km are included on the map. The images contrasts are in most cases related to topographic changes and the lineament is lying predominantly along topographic flat-lying areas up to 1 km across. These topographic changes are thought to represent linear zones of weakness in the bedrock i.e. related to tectonic structures. Correlations with mapped geological structures have not been published. The map does not include a classification into different lineaments. Location of the lineament is correct to +/- 1.5 km perpendicular to the lineament strike.

The Relief map is made by computer technique based on heights within 500m grid system.The data is derived from topographic maps at a scale of 1: 50 000. The accuracy is estimated to +/- 10m. The map is presented by hill shading technique with an oblique illumination from northwest. The final map, at a scale of 1: 2 000 000, is derived from about 2 million height values.

The lineaments evaluated from the Relief map is only based on topographic data, Non topographic lines as vegetation contrasts, railway and road tracks etc. will not appear. The lineaments based on the Relief map therefore represents traces of topographic significance as valleys, hills, escapments ets., which in most cases have a geological origin as tectonic structures and geological boundaries.

According to Elvhage and Lidmar-Bergström (1987), their investigations in two different areas, one in a region with high relative relief and one in an area of low relative relief, show that the main lineaments are correlated with distinct valleys on the topographic map.

4.1 CORRELATION OF LINEAMENTS WITH KNOWN TECTONIC STRUCTURES

A correlation test has been performed in order to check the validity of the relatations between lineaments from the Relief map and published tectonic main structures.

The area of the test includes the geological maps SGU Ser Ba39 and Ba 34, at a scale of 1:250 000,which cover a large area in southeast Sweden. These geological maps includes 219 tectonic structures, of which 185 structures to location and direction coincide with lineaments on map (Figure 7).The missing structures where small or laying close to a larger structure and therefore could not be separated from the main structure at the scale used (1:2 000 000). The length of the lineament seldom corresponded with the length of the structures.

4.2 THE LINEAMENT MAP BASED ON LANDSAT IMAGES

Figures 5 and 6 are interpretations made from the Lineament map based on Landsat images III.

Figure 5 is a map showing the density and orientation of all lineamants observed on the Landsat images. The density has been evaluated by measuring the number of lineaments in steps of 50 km in an east-west direction. The orientation is taken for the predominating lineament of each region.

The visibility of the lineaments are dependent on the topographic relief and thickness of soil cover. Therefore the density map may not reflect the true density of geological structures in the bedrock.

Figure 6 shows the lineaments that have a length greater then 50 km or where two lineamants are alined in the same direction, one of which has a length greater then 30 km.

The map reflects the large structures in the bedrock and by compare Figure 6 and Figure 4 it is obvious that known large tectonic structures in the basement are identified on the lineament map. It seems reasonable to assume that most of the other lineaments also can be correlated with large tectonic zones in the basement.

4.3 THE LINEAMENT MAP BASED ON THE RELIEF MAP

The lineaments evaluated from the Relief map is shown on Figure 7, 8 and 9.

Figure 7 is the base lineament map evaluated from two Relief maps with illumination from northwest and west. Two directions were selected in order to increase the information in areas of low relief and in areas where the topographic orientation was subparallel to one of the directions of the illumination.

Areas with low lineament density occur in south and southeast most parts of Sweden, the area between the lakes Vänern and Vättern, east of lake Vättern, a northeast oriented belt from the north tip of lake Vättern, areas northwest of lake Siljan, and northern most part of the country.

Lineaments with a length larger then 50 km or two combined lineaments with the same direction of which one lineament has a length greater then 30 km are shown with full line on Figure 8. The dashed lines are lineaments from the Landsat images , Figure 6, that correspond in the location and direction with lineaments on the Relief map.

There is an acceptable correlation between the two types of lineament maps in southern Sweden. Lineaments observed on the Relief map can in most cases be found on the Landsat images.

On the north map of Sweden , Figure 8, this correlation is not obvious.Here only the lineaments with directions in NNW-SSE will correspond. Lineaments with directions in

WNW-ESE are almost missing on the Landsat images (cf Figure 6). The dominating lineament observed on the Landsat images is oriented in NW-SE.

Figure 9 shows a subdivision into regions , where each region have the same orientation of the lineaments. A grading of the orientations is made by the notation. The first direction in the notation is the most dominating in each area.

The area west of the Protogine zone is dominated by lineaments oriented towards N and NE. The orientation along the Protogine zone is normally N and NE. The southeast part of Sweden is dominated by directions in NW and NNW. South-central and central Sweden has a predominating orientation in EW, while north Sweden is dominated by orientations in NW, WNW and NNW.

Lineaments based on the Relief map correlates very well with topographic features, which in most cases have a tectonic origin. It seems therefore reasonable to assert that this lineament map, Figure 7, to great extent reflects the large scale tectonic pattern of the bedrock in Sweden.

5. REFERENCES

Atlas över Sverige; 1957: Höjd och djupförhållanden. Nr 1-2
Atlas över Sverige; 1953: Landytans brutenhet. Nr 3-4
Atlas över Sveige; 1967: Tyngdkraft, stratigrafi och tektonik, Geomorfologi. Nr 5-6.

Elvhage,Ch. and Lidmar-Bergström,K.; 1987: Some working hypotheses on the geomorpology of Sweden in the light of a new relief map. Geografiska Annaler. 69A, pp 343-356.

Ehrenborg,J.; 1984: Lineament map of Sweden. SGU Ser Ba 33. Only maps.

Gaal,G. and Gorbatschev,R.; 1987: An outline of the Precambrian evolution of the Baltic Shield. Precamb. Research. Vol 35.

Magnusson,N.H., Thorslund,P.,Brotzen,F.,Asklund,B. and Kulling,O.; 1962: Beskrivning till karta över Sveriges berggrund. SGU Ser Ba nr 16.

Larsson,S., Stigh,J. and Tullborg, E.-L.; 1986: The deformation history of the eastern part of the southwest swedish gneiss belt. Precamb. Research. Vol 31.

Lind,A.; 1987: Westward growth of the Baltic Shield. Precamb. Research. Vol 35.

Loberg,B. 1987: Geologi. Norstedts.

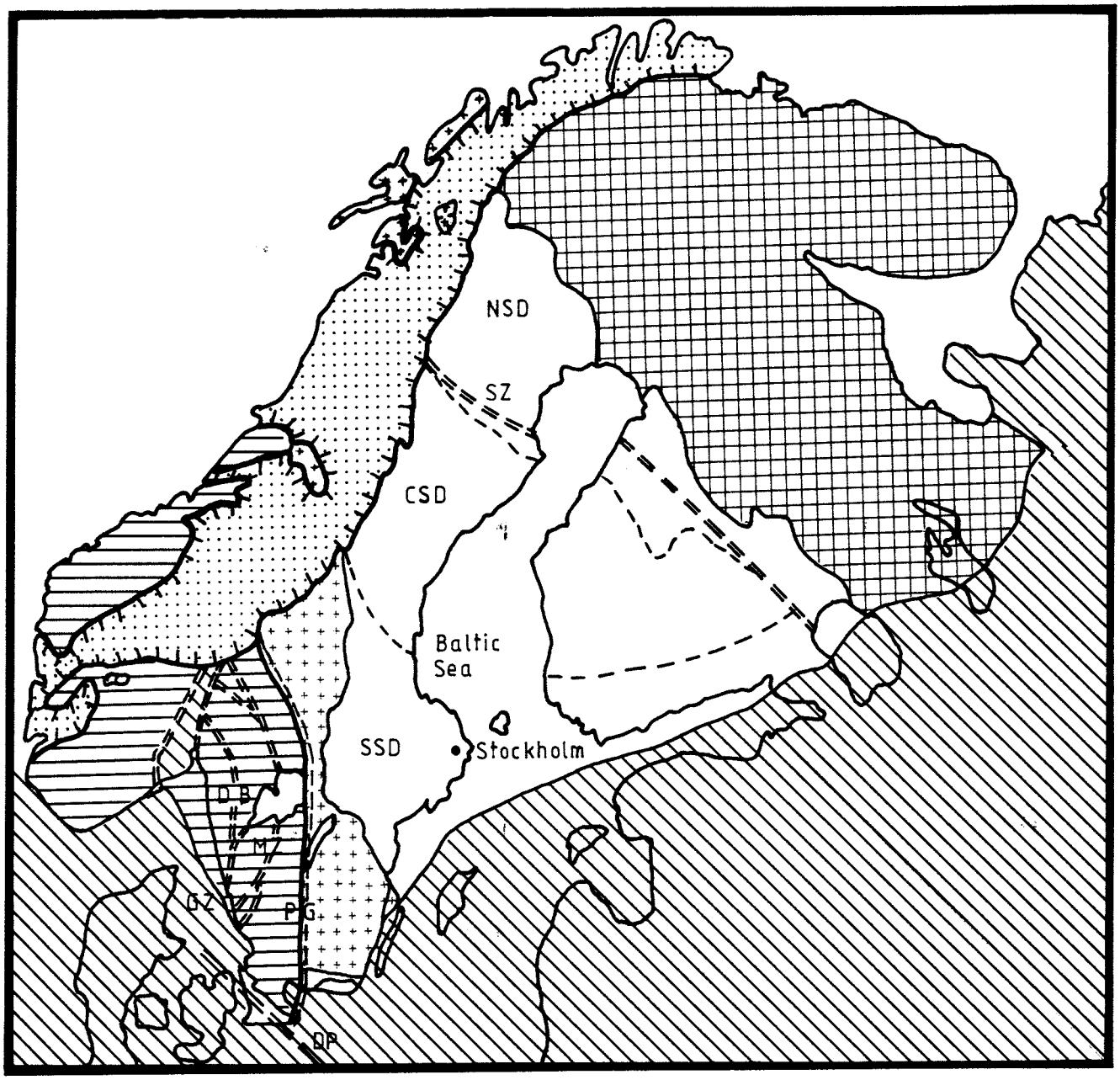
Lundström,I.; 1987: Lateral variations in supracrustal geology within the Swedish part of the southern Svecokarelian volcanic belt. Precamb. Research. Vol 35.

Lundqvist, Th.; 1987: Early Svecofennian stratigraphy of southern and central Norrland, Sweden, and the possible existens of an Archaean basement west of the Svecobarelides. Precamb. Research. Vol 35.

Rudberg,S.; 1970: Gravity, Stratigraphy and Tectonics. Geomorphology.Atlas över Sverige, Nr 5-6.

Röshoff,K.; 1979: The tectonic-fracture pattern in southern Sweden. Geol Fören Förh. Vol 100, pp 255-261.

Welin,E.; 1987: The depositional evolution of the Svecofennian supracrustal sequences in Finland and Sweden. Precamb. Research. Vol 35.



DB Dalsland Fault
DP Danish-Polish Trough
MZ Mylonite Zone
PG Protogine Zone
GZ Göta älv Zone
SZ Skellefte Zone

NSD North Svecofennian Domain
CSD Central Svecofennian Domain
SSD South Svecofennian Domain

== Tectonic major zone
== Tectonic zone
—⊤— Thrust, Caledonien orogeny
-- Subdomain boundary

Archaean Domain
Svecofennian Domain
Southwest Scandinavien Domain
Transscandinavian granite - porphyry belt
Caledonides
Phanerozoic sedimentary rocks

FIGURE 1. Major subdivision of bedrock and tectonic structures of the Baltic Shield
(Mainly after Loberg 1987)

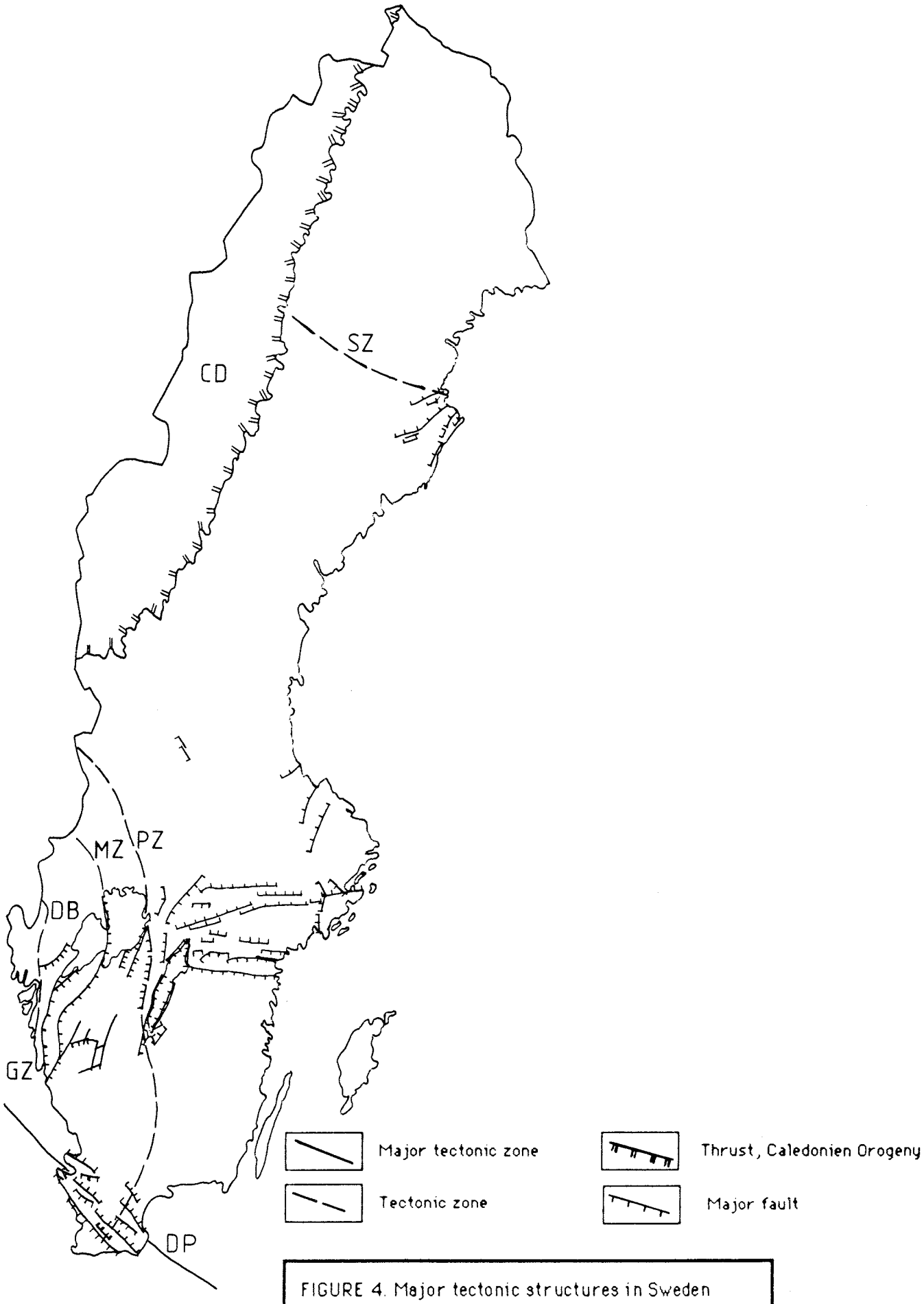
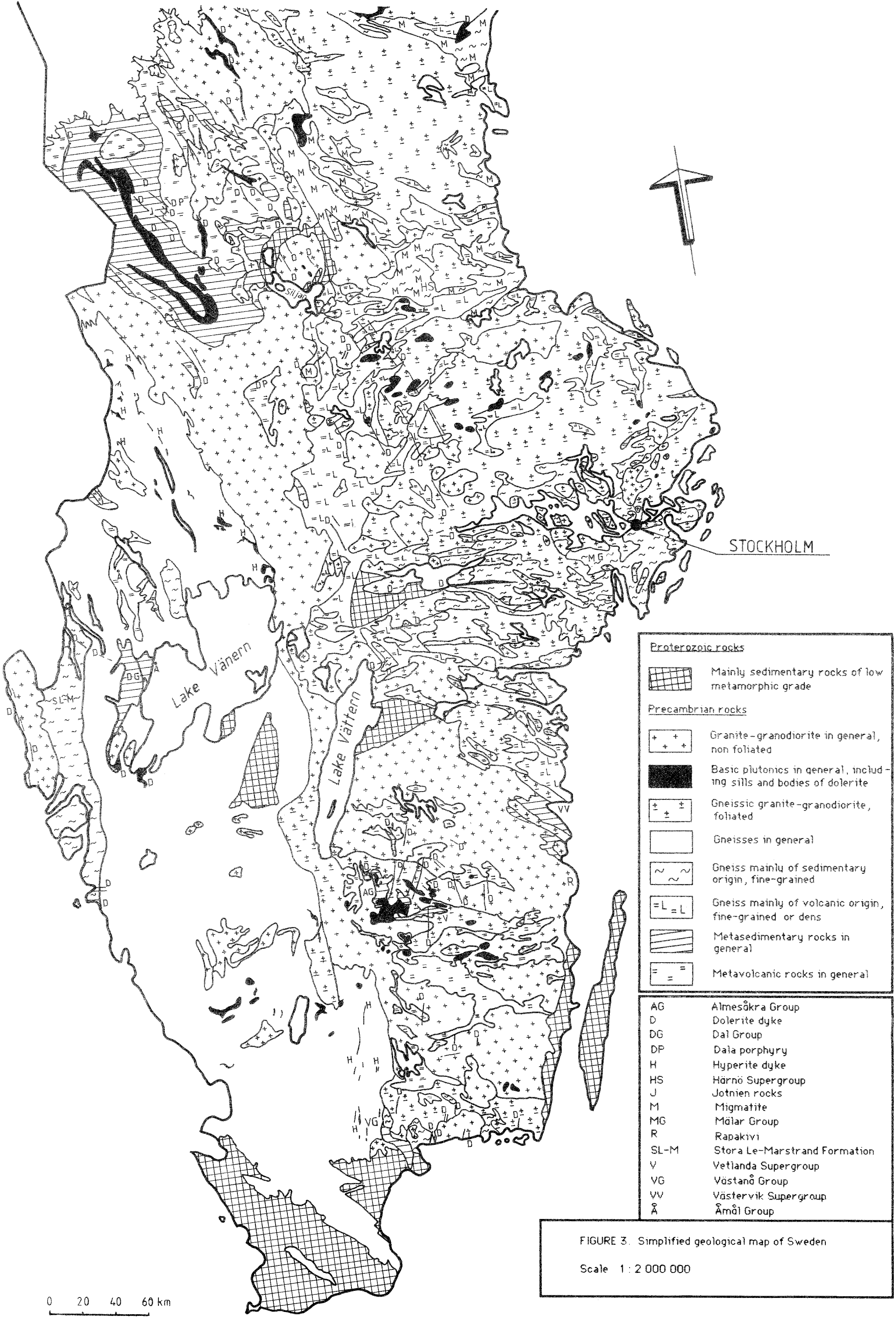


FIGURE 4. Major tectonic structures in Sweden

CD Caledonien orogeny
DB Dal Boundary fault
DP Danish-Polish trough
GZ Göta älv zone
PZ Protogine zone
SZ Skellefteå zone



Proterozoic rocks

- Mainly sedimentary rocks of low metamorphic grade

Precambrian rocks

- Granite-granodiorite in general, non foliated
- Basic plutonics in general, including sills and bodies of dolerite
- Gneissic granite-granodiorite, foliated
- Gneisses in general
- Gneiss mainly of sedimentary origin, fine-grained
- Gneiss mainly of volcanic origin, fine-grained or dens
- Metasedimentary rocks in general
- Metavolcanic rocks in general

AG	Almesåkra Group
D	Dolerite dyke
DG	Dal Group
DP	Dala porphyry
H	Hyperite dyke
HS	Härnö Supergroup
J	Jotnien rocks
M	Migmatite
MG	Mälar Group
R	Rapakivi
SL-M	Stora Le-Marstrand Formation
V	Vetlanda Supergroup
VG	Västanå Group
VV	Västervik Supergroup
Å	Åmål Group

FIGURE 3. Simplified geological map of Sweden

Scale 1 : 2 000 000

Proterozoic rocks

Mainly sedimentary rocks of low metamorphic grade

Precambrian rocks

Granite-granodiorite in general, non foliated

Basic plutonics in general, including sills and bodies of dolerite

Gneissic granite-granodiorite, foliated

Gneisses in general

Gneiss mainly of sedimentary origin, fine-grained

Gneiss mainly of volcanic origin, fine-grained or dens

Metasedimentary rocks in general

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CALEDONIDES

AG	Almesåkra Group
D	Dolerite dyke
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FIGURE 3 Simplified geological map of Sweden

Scale 1 : 2 000 000

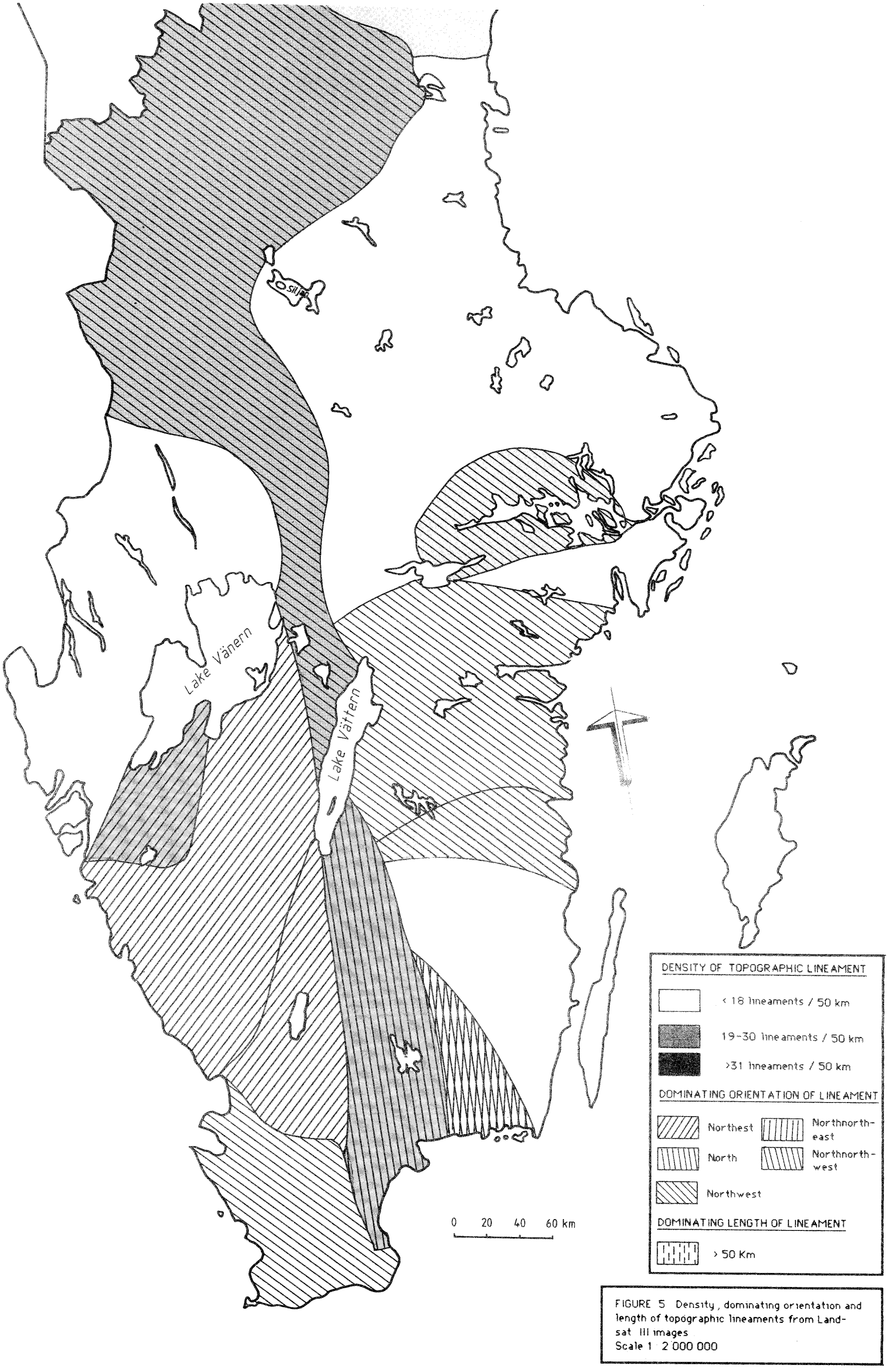


FIGURE 5 Density, dominating orientation and length of topographic lineaments from Landsat III images
Scale 1 2 000 000

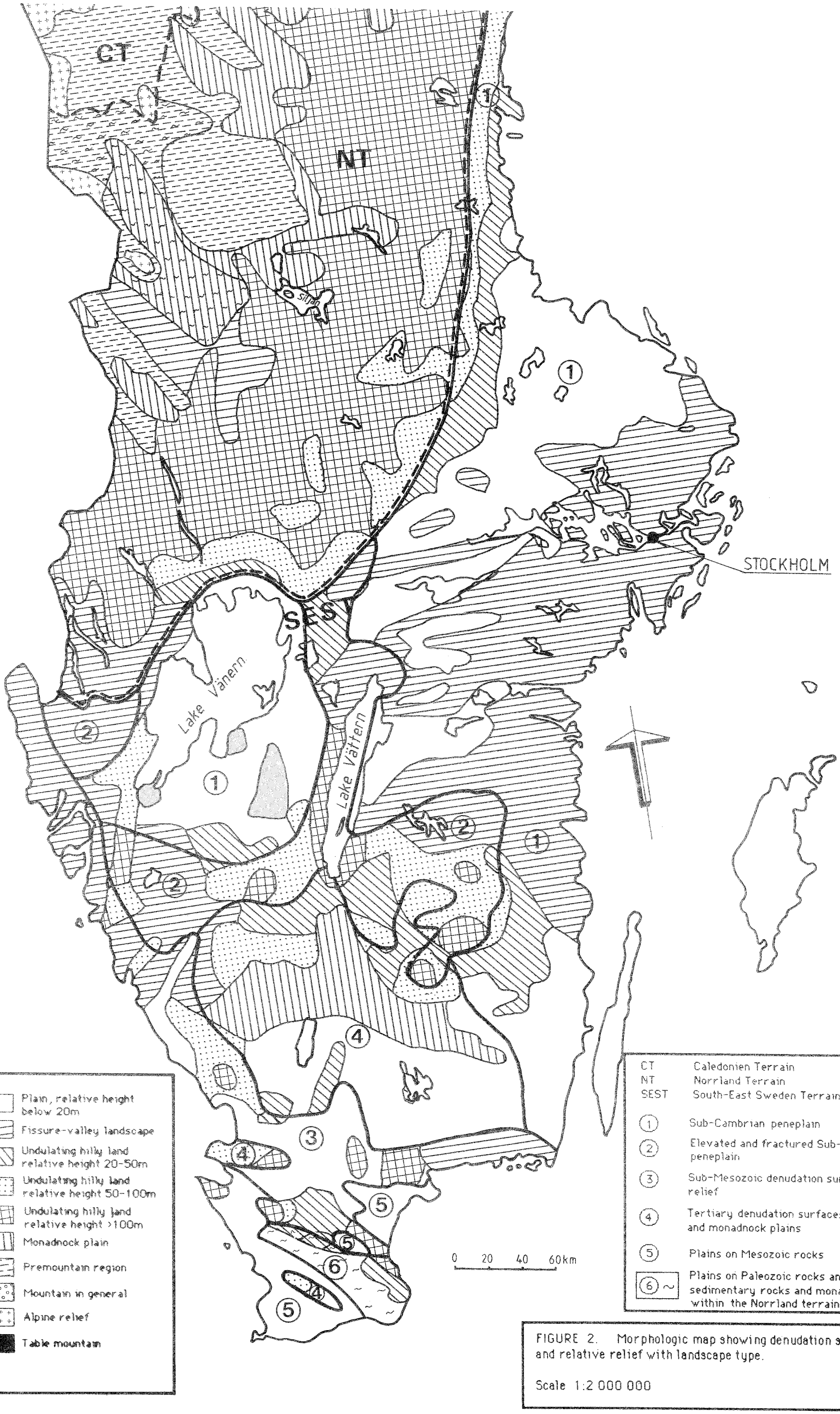
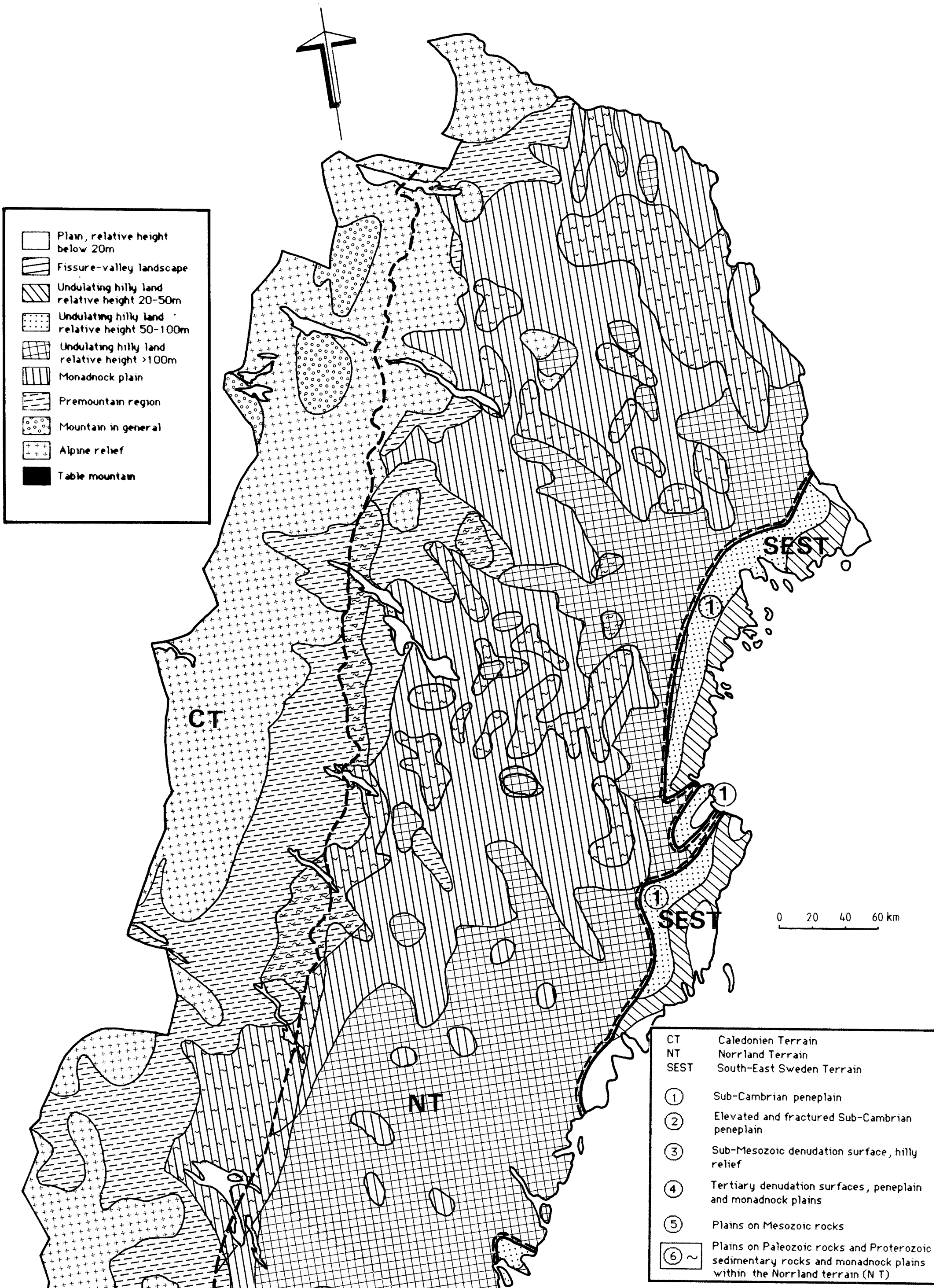


FIGURE 2. Morphologic map showing denudation surfaces, and relative relief with landscape type.

Scale 1:2 000 000



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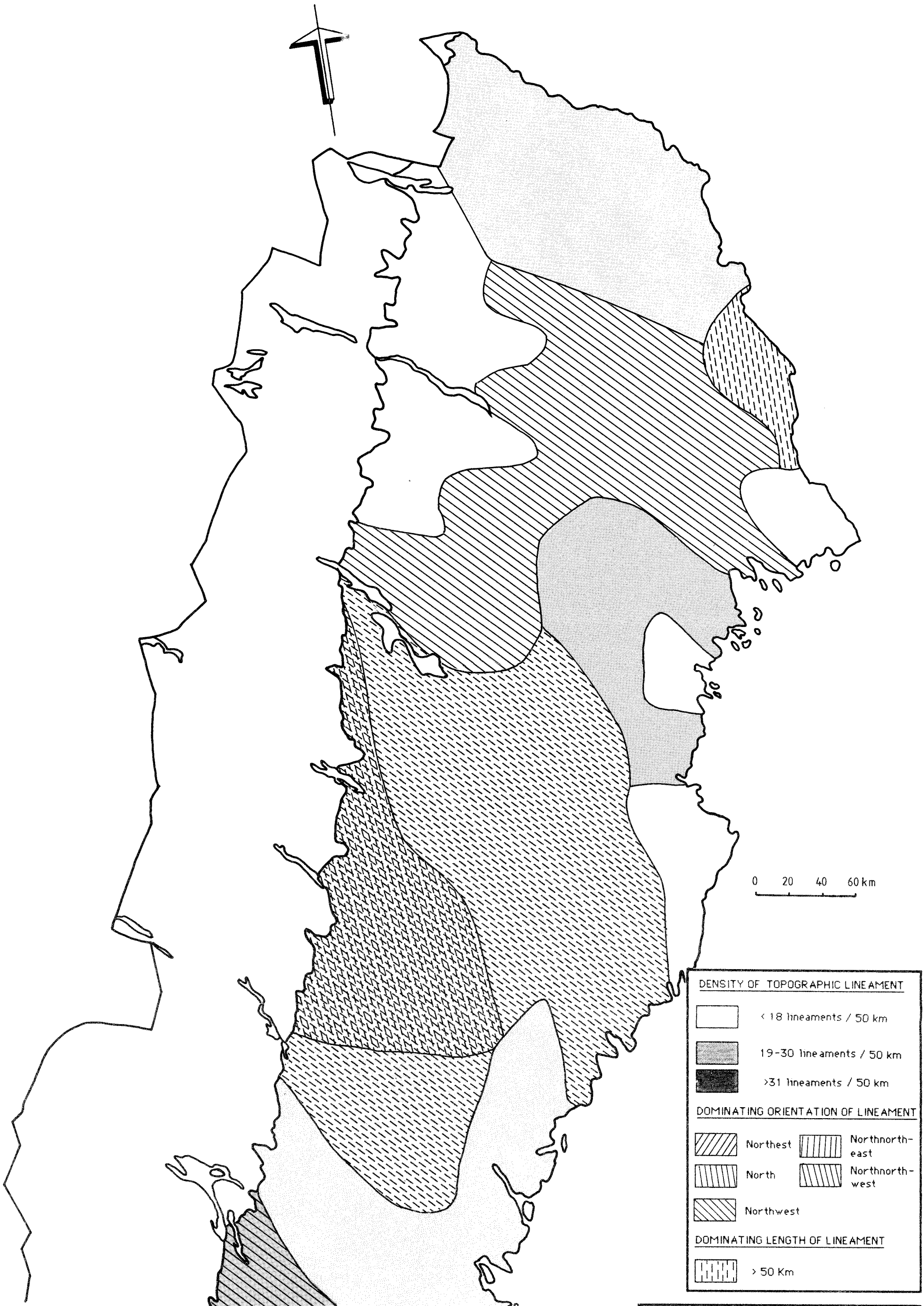

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Scale 1 : 2 000 000

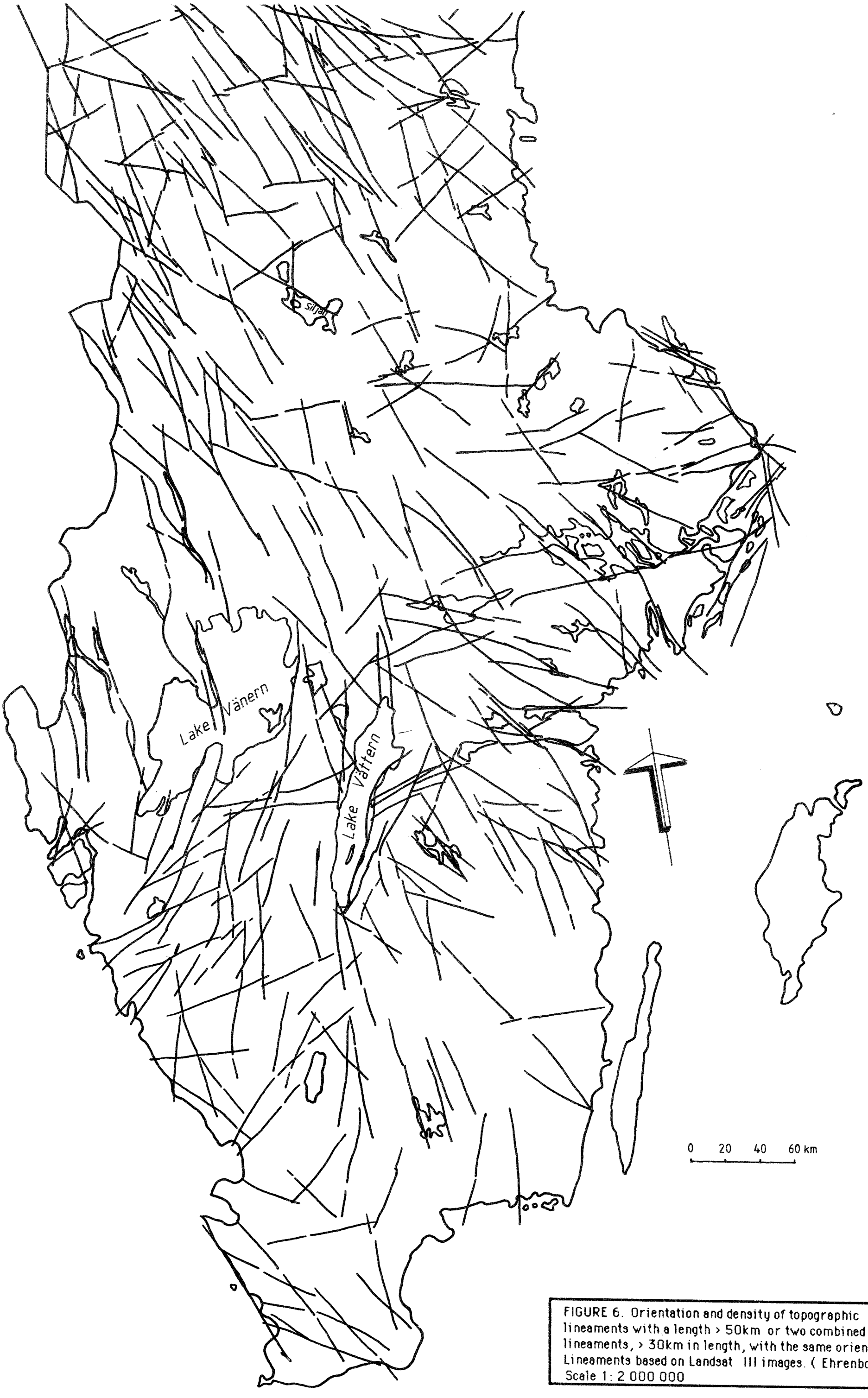

FIGURE 6. Orientation and density of topographic lineaments with a length > 50km or two combined lineaments, > 30km in length, with the same orientation. Lineaments based on Landsat III images. (Ehrenborg 1984). Scale 1: 2 000 000

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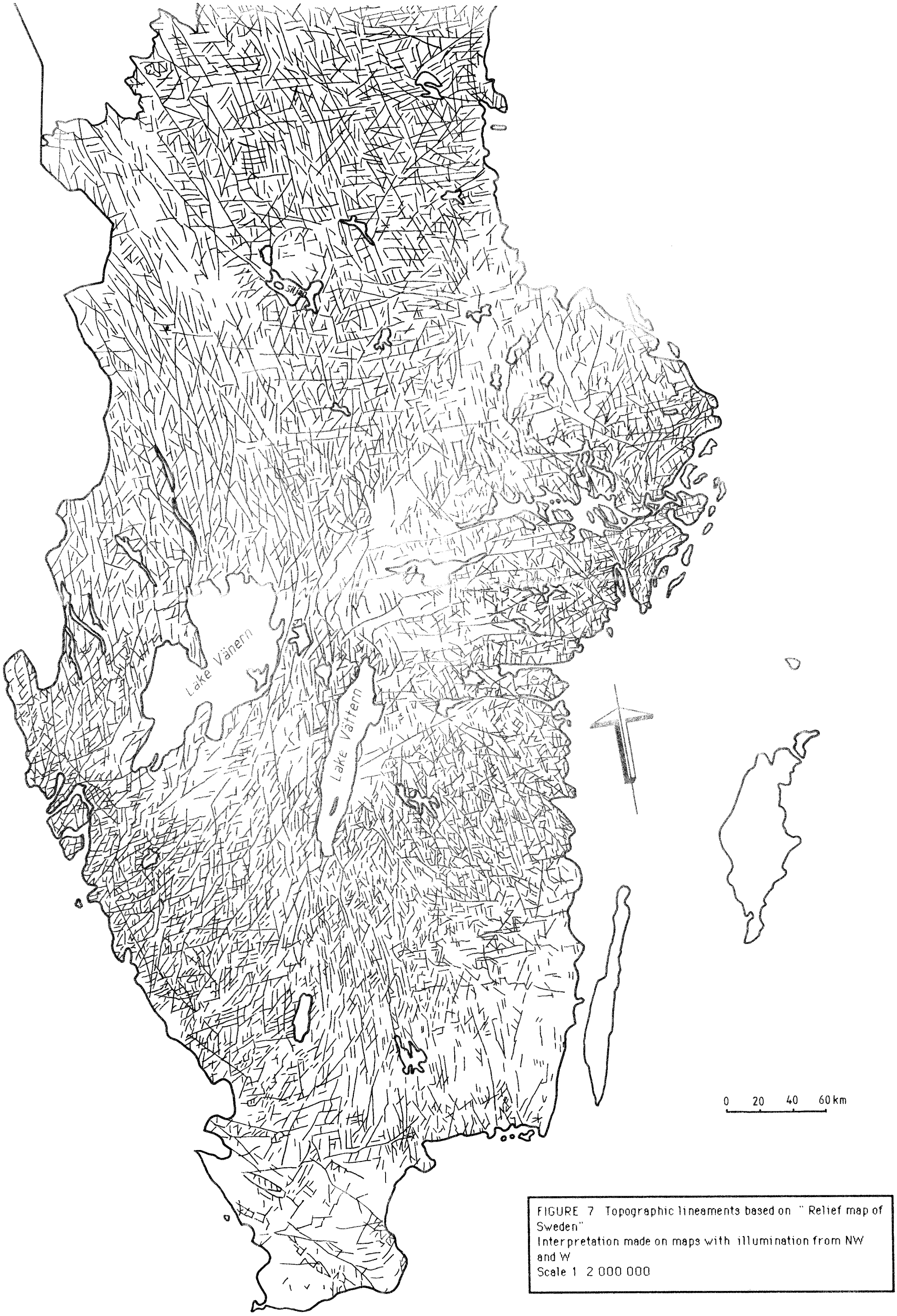
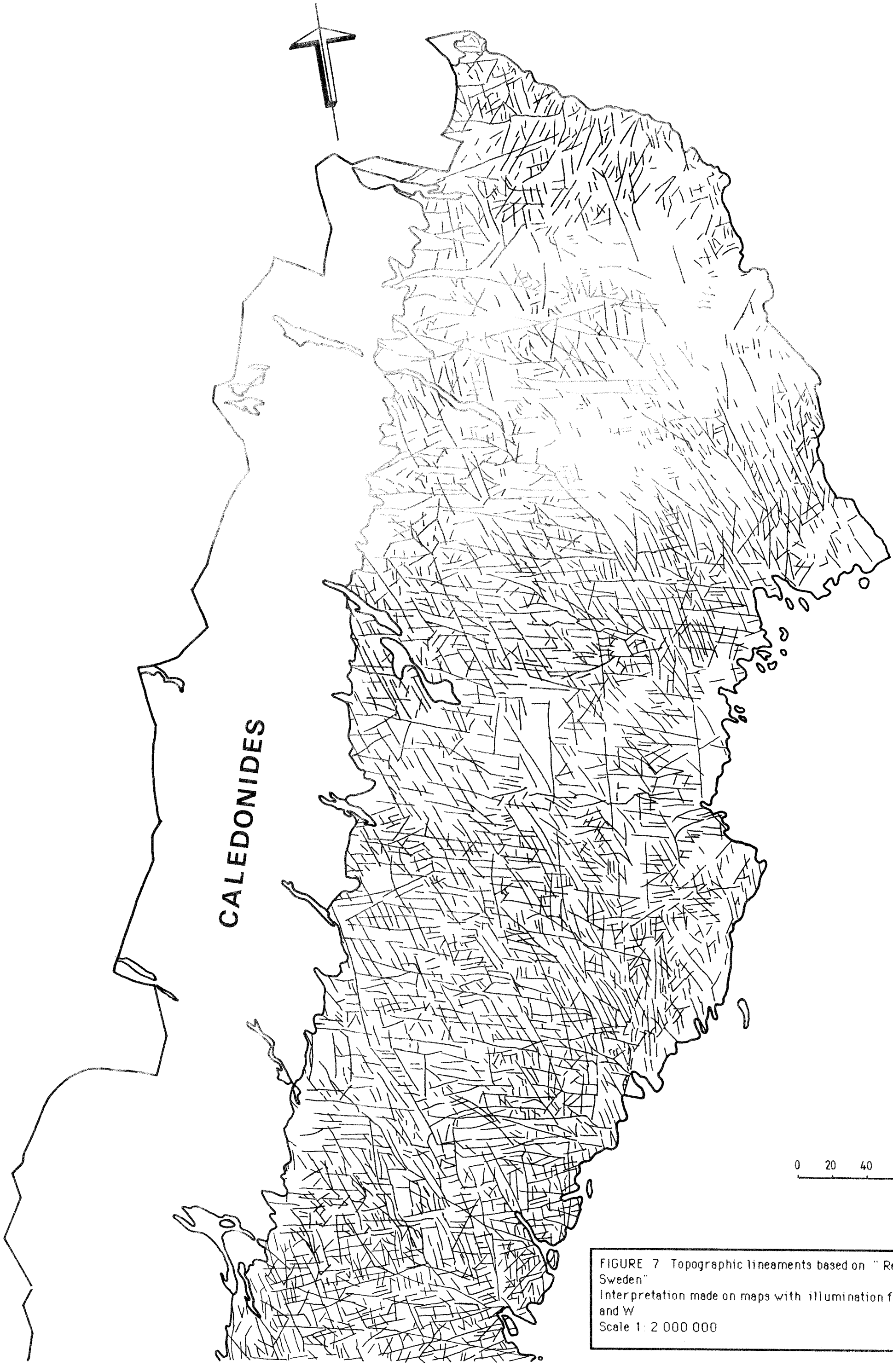


FIGURE 7 Topographic lineaments based on " Relief map of Sweden"
Interpretation made on maps with illumination from NW and W
Scale 1 2 000 000



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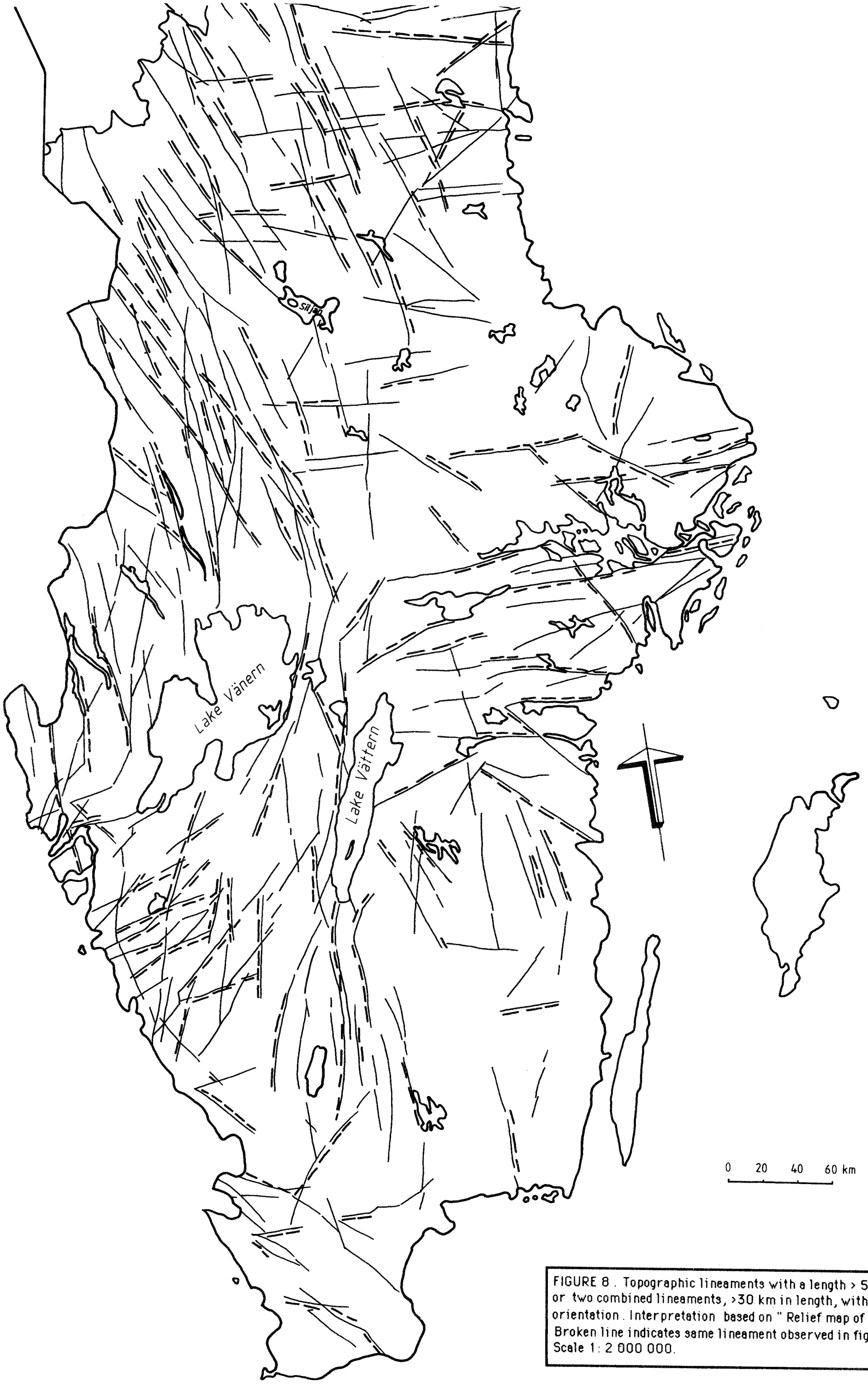
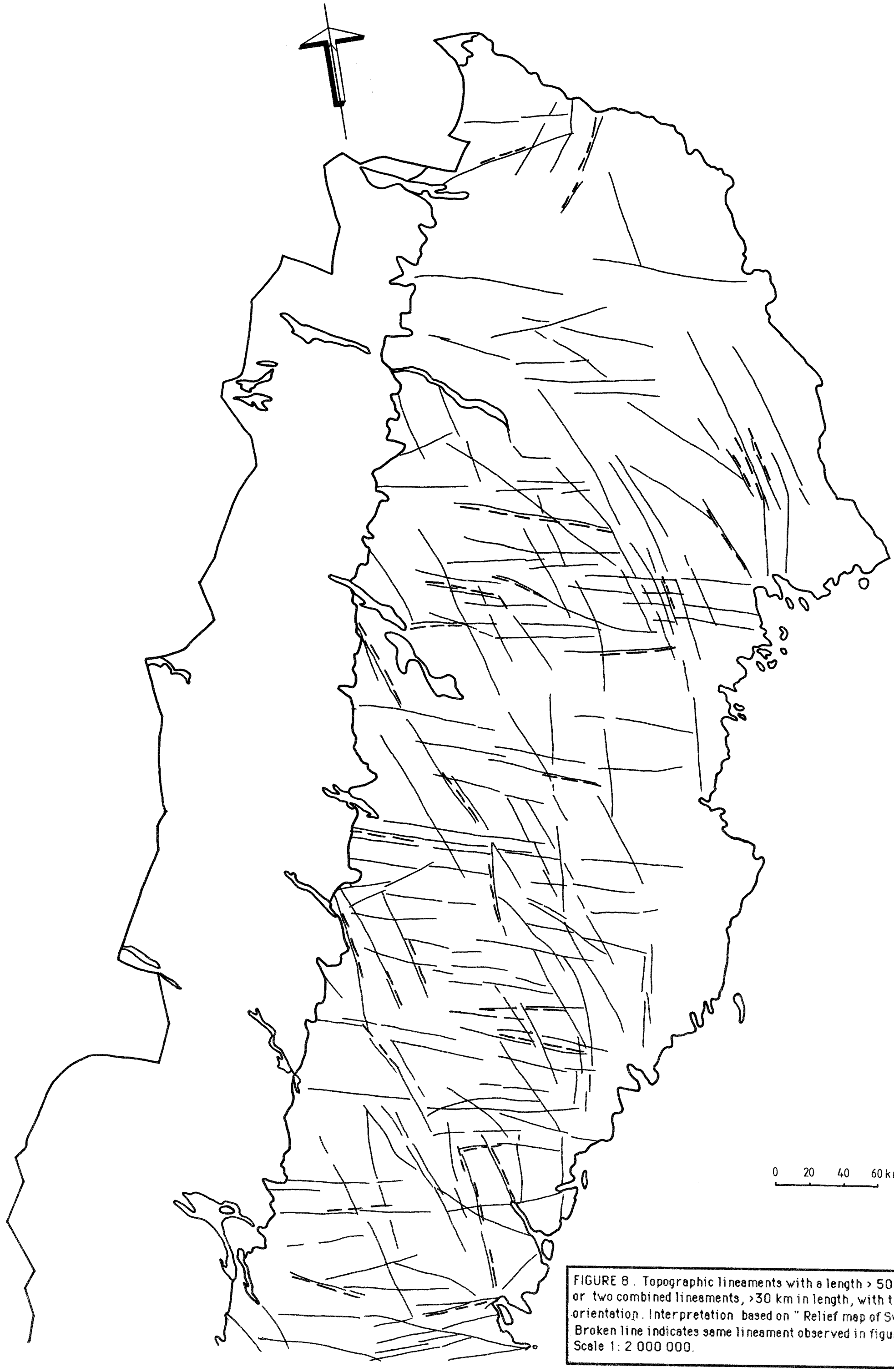


FIGURE 8 . Topographic lineaments with a length > 50 km or two combined lineaments, >30 km in length, with the same orientation . Interpretation based on " Relief map of Sweden" Broken line indicates same lineament observed in figure 6. Scale 1: 2 000 000.



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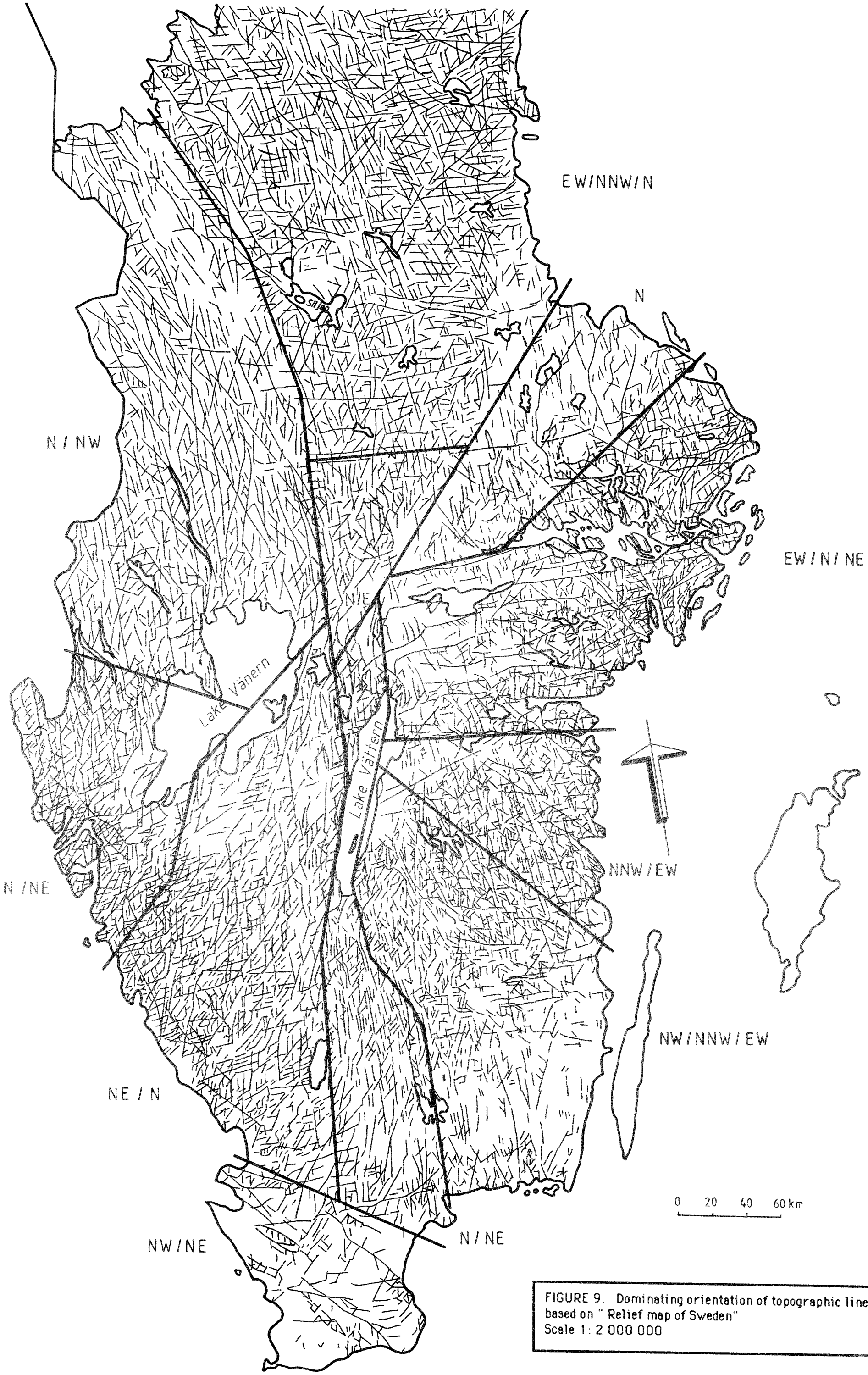

FIGURE 9. Dominating orientation of topographic lineaments based on " Relief map of Sweden"
Scale 1: 2 000 000

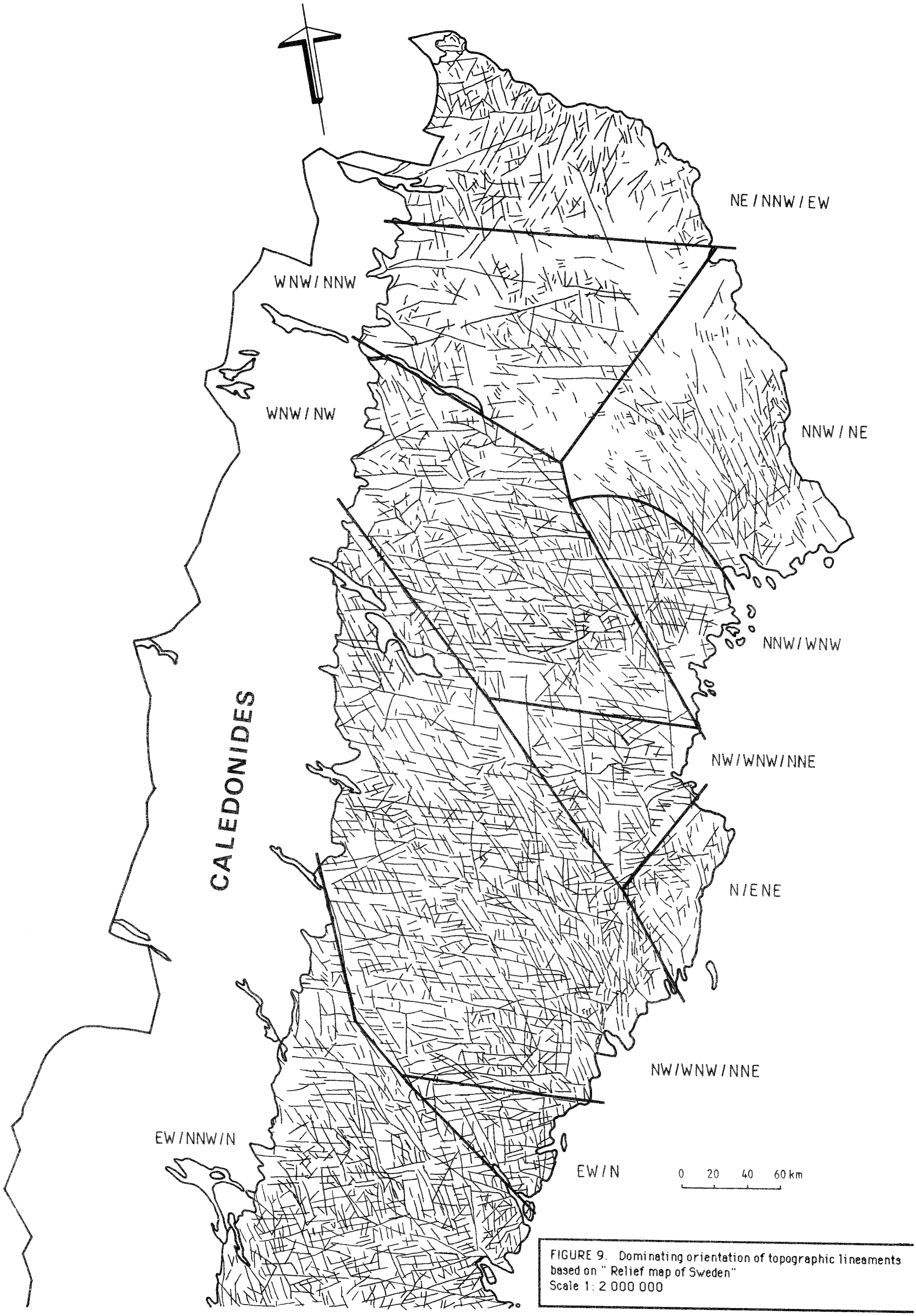

FIGURE 9. Dominating orientation of topographic lineaments based on " Relief map of Sweden"
Scale 1: 2 000 000

List of SKB reports

Annual Reports

1977–78
TR 121
KBS Technical Reports 1 – 120.
Summaries. Stockholm, May 1979.

1979
TR 79–28
The KBS Annual Report 1979.
KBS Technical Reports 79-01 – 79-27.
Summaries. Stockholm, March 1980.

1980
TR 80–26
The KBS Annual Report 1980.
KBS Technical Reports 80-01 – 80-25.
Summaries. Stockholm, March 1981.

1981
TR 81–17
The KBS Annual Report 1981.
KBS Technical Reports 81-01 – 81-16.
Summaries. Stockholm, April 1982.

1982
TR 82–28
The KBS Annual Report 1982.
KBS Technical Reports 82-01 – 82-27.
Summaries. Stockholm, July 1983.

1983
TR 83–77
The KBS Annual Report 1983.
KBS Technical Reports 83-01 – 83-76
Summaries. Stockholm, June 1984.

1984
TR 85–01
Annual Research and Development Report 1984
Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01–84-19)
Stockholm June 1985.

1985
TR 85-20
Annual Research and Development Report 1985
Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01-85-19)
Stockholm May 1986.

1986
TR 86-31
SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

1987
TR 87-33
SKB Annual Report 1987
Including Summaries of Technical Reports Issued during 1987
Stockholm, May 1988

1988
TR 88-31
SKB Annual Report 1988
Including Summaries of Technical Reports Issued during 1988
Stockholm, May 1989

Technical Reports

1989
TR 89-01
Near-distance seismological monitoring of the Lansjärv neotectonic fault region Part II: 1988
Rutger Wahlström, Sven-Olof Linder, Conny Holmqvist, Hans-Edy Mårtensson
Seismological Department, Uppsala University, Uppsala
January 1989

TR 89-02
Description of background data in SKB database GEOTAB
Ebbe Eriksson, Stefan Sehlstedt
SGAB, Luleå
February 1989