GEOLOGY OF EUROPE: A SYNTHESIS

by

Jean Aubouin

Europe is a "continental crossroads" rather than a continent in itself: crossroads of orogenies, crossroads of oceanic openings, crossroads of climates, it exemplifies in rather limited space, all the geological problems that arise on a continental scale. In this article, the President of the 26th International Geological Congress traces Europe's complex geological history and accounts for some of its ambiguities.

Two oceans - the Atlantic and the Arctic - bound Europe on the west and north with broad continental shelves. Its eastern and southern boundaries are somewhat more varied. The Urals to the east, a Hercynian chain, welded the North Atlantic continent to Asia in the Permian and established Eurasia, which was to define its identity after the opening of the Tethys in the Triassic and Jurassic, and later the Atlantic in the Cretaceous and Tertiary. The Lesser Caucasus, an Alpine chain to the south, developed on the southern margin of Eurasia and represent the northern branch of the Alpine orogen. (The Greater Causasus are generally considered as part of Europe, even though they represent the true mountain barrier.)

Intramontane seas formed in the final phases of the Alpine orogeny - the Caspian, Black and Aegean Seas, as well as the Mediterranean. The Straits of Gibraltar were formed in their present position in the Pliocence, as were both the Aegean Sea and the Sea of Marmara which fix the alignment of the Dardanelles and the Bosphorus.

The Hercynian orogeny played a key role in defining Europe as such, since it led to the formation of Eurasia. Before that, the history of Europe was that of "Euramerica": the Caledonian and Hercynian chains of western Europe continued naturally into Greenland and North America. Later on in the Alpine orogeny, "Eurafrica" predominated, the North African chains having an obvious kinship to the Alpine chains of Mediterranean Europe.

Tectonics of Europe

Four tectonic ensembles, each defined by a corresponding orogeny, subdivide Europe: Precambrian Europe is considered as a whole, for its chronological divisions do not form distinct natural regions; the others are Caledonian or northwest Europe, Hercynian (Variscan) or southwest Europe, and Alpine or Mediterranean Europe (Fig. 1). Central Europe developed at the crossroads of these different orogenies.

Precambrian Europe

The Precambrian forms three complexes in Europe: the *shields* in which the Precambrian crops out, undeformed through the whole of Phanerozoic time; the *nuclei*, caught up in later orogenies; and the Russian *platform*, where a horizontal Phanerozoic cover rests with little or no deformation on a permanently stable Precambrian basement.

The shields include the Baltic Shield (or Fennoscandia) which forms the greater part of Sweden, Finland and the Russian border area, including the floor of the Barents Sea; the Ukrainian Shield, which crops out southwest of the Russian Platform (of which it forms the foundation); and the Hebridean Shield (or Eria) in the northern part of the British Isles, which may also be considered as a nucleus caught up in the Caledonian orogeny.

The shields are characterized by their relatively great antiquity: their metamorphic rocks are older than 1500 Ma and covered by detrital red beds of late Proterozoic age.

Precambrian nuclei are found in the younger Caledonian and Hercynian chains, especially along the axis of the central European cordillera: the Armorican Massif, Massif Central, Vosges, Black Forest and Bohemia, and in the axis of the Iberian meseta. In the Alpine chain, they are on the axis of the Dinaride-Balkan complex - the Serbo-Macedonian and Rhodope massifs.

If younger Precambrian material is found in these nuclei (as

"U" shaped valley of Aurlandsfjord, from above Aurlands, West Norway: Precambrian crystallines of the Caledonian Upper Jotun Nappe. (Photo courtesy National Museum of Wales)

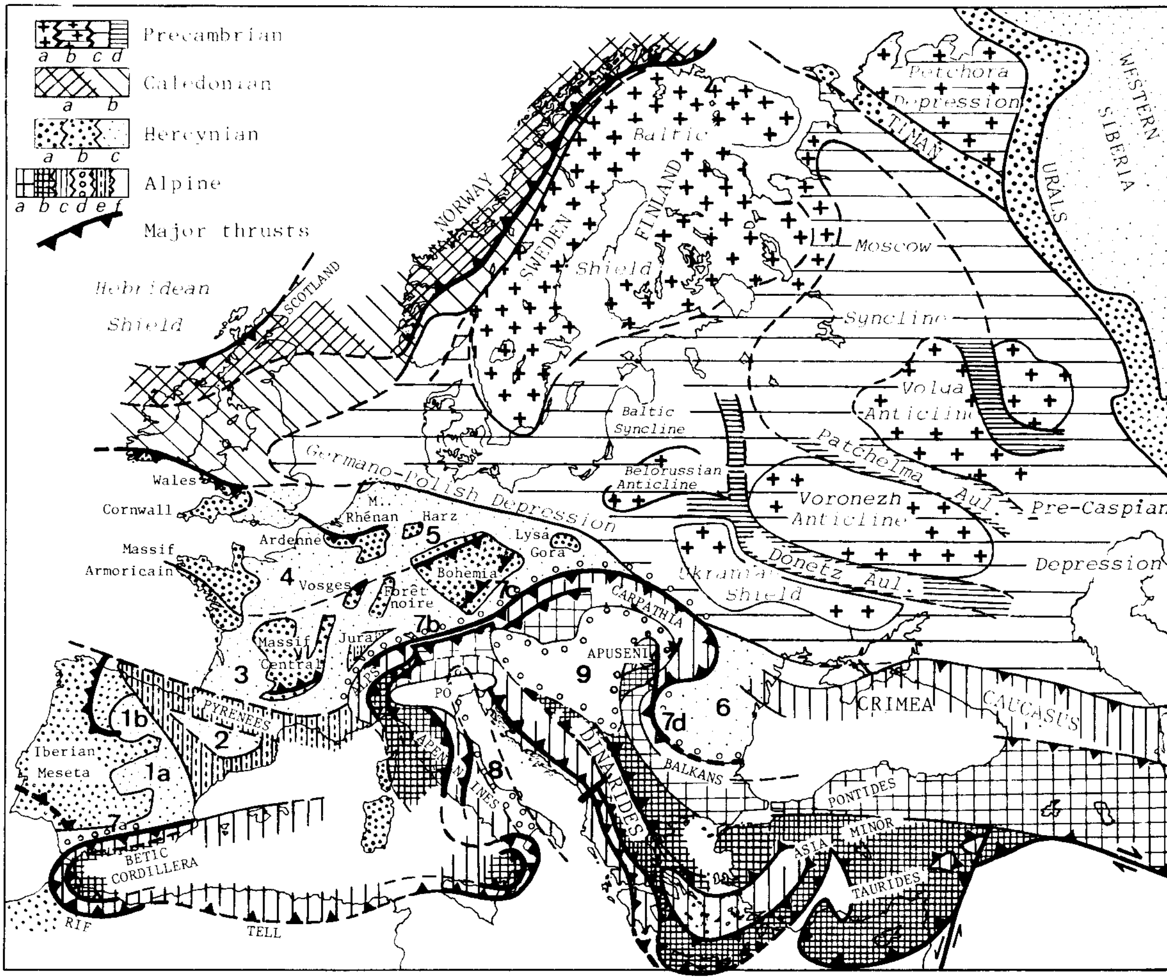

Figure 1. Structural Outline of Europe: *Precambrian: a) Shields, b) Anteclises; Uplifted areas of continental platform, c) Syneclises; Depressed areas of continental platform, d) Aulacogen. Caledonian: a) Internal metamorphic zones and/or ophiolites, b) External weakly metamorphosed zones. Hercynian: a) Internal metamorphic zones, b) External zones, c) Hercynian platform. Alpine: a) Internal zones in general, b) Internal metamorphic zones and/or ophiolites, c) External zones, d) Molasse, e) Intracontinental Mountain Chains, f) Pliocene-Quaternary. 1 Castillian Basins (1a - Nouvelle Castille, 1b - Vieille Castille), 2 Ebre Basin, 3 Aquitaine Basin, 4 Anglo-Paris Basin, 5 Assemblage of German Basins, 6 Dacique Basin, 7 Alpine foredeep (7a - Guadalquivir, 7b - Alpine foredeep proper, 7c - Peri-Carpathic foredeep, 7d - Balkan foredeep) 8 Italo-Dinaric foredeep, 9 Pannonique Basin (backdeep).*

in the Pentevrian of northern Brittany and the Channel Islands), it consists chiefly of late Precambrian formed in marine environments around the periphery of the Precambrian shields. In many cases the rocks are of oceanic facies (radiolarite and flysch) and the oceanic crust itself may be represented by ophiolites. (The Brioverian of western Europe, a regional equivalent of the Rhiphean of Asia, serves as an example.)

These areas were affected at the end of the Precambrian by an orogeny called the Cadomian of western Europe - the equivalent of the Panafrican orogeny which developed in Africa and South America, the Baikalian in Asia and, in a more general way, the Assyntic orogeny as well. The Cadomian orogeny was accompanied and/or followed by an early Cambrian glaciation of which tillites, in the form of moraines, are found around the Scandinavian Shield or as redeposited marine sediments in the Armorican Massif.

The Russian Platform is overlain by formations that have remained horizontal since the Cambrian. Their deformation is on the thousand-kilometre scale, whether anticlinal (as the anteclises of Byelorussia, Voronezh and the Volga) or synclinal (the Baltic and Moscow syneclises), or in the form of troughs (the aulacogens of Donetz and Patchelma). On its southern border, the platform is fringed by a marginal depression which is more pronounced to the southwest and southeast (the Germano-Polish and Pre-Caspian depressions); Permian saliferous deposits are abundant in both, and give rise to numerous salt domes.

Caledonian Europe

The Caledonian of Europe manifests itself in Scandinavia (Norway, the Swedish borders and Spitzbergen) and in most of the British Isles except for the southernmost part. It originated in a Caledonian geosyncline to the west of the Baltic Shield; its oceanic crust formed Caledonian ophiolitic nappes.

The Caledonian chain is a typical *collision chain* of opposing vergences, one side directed toward the Baltic Shield (Spitzbergen, Scandinavia, British Isles), the other toward the Canadian Shield or Laurentia (East Greenland). The natural continuation of this structure is in Canada (Newfoundland, Maritime Provinces, southern Québec) and northeastern United States (Allegheny Mountains). Nappes form a prominent feature in Scandinavia and the British Isles, constituting some of the earliest nappe complexes in the world to have been described (by Geikie in Scotland and by Tornebohm in Scandinavia).

Identification of the Caledonian orogeny in the rest of Europe is difficult because it has been caught up in the Hercynian and Alpine orogenies. The nature of the problem varies: it is a stratigraphical issue where the Devonian rests unconformably on formations once thought to be Precambrian (Brioverian), but which are now known in many cases to be of Lower Palaeozoic age (as with the Armorican Massif, especially in the Vendée). It is a chronological problem for granites once thought to be Hercynian, but which now appear to be Caledonian according to radiometric determinations (as, for example, in the Massif Central). It is a tectonic problem where the Ardennes deformation, lying to the south of the Russian Platform and its continuation, reveals structures with a northward vergence, implying that the Ardennes Caledonian represented only the margin of the chain, while the main part lay to the south.

Hercynian (Variscan) Europe

The Hercynian is represented in most of the ancient massifs of central and western Europe which are separated from one another by Mesozoic and Tertiary sedimentary basins, or by Tertiary troughs linked with the Alpine orogeny. Thus, while the structure of Caledonian Europe is obvious, that of the Hercynian must be reconstructed in the mind.

One could say that Hercynian Europe consists of two chains with opposing vergence. The central European cordillera, extending from southern Britain through France, Germany and Czechoslovakia, lies on the edge of the north Atlantic continent; the latter forms its foreland and is separated from it by a molassic foredeep in which the Coal Measures of Middle Carboniferous age were deposited. The cordillera has a Precambrian axis which was metamorphosed and granitized during the Hercynian cycle; it extends from southern Brittany through the Massif Central, Vosges, the Black Forest to Bohemia.

In the north it displays structures that are overturned or thrust northward (the Condroz nappes of the Harz, and the Sudeten Mountains); to the south, the structures are thrust southward (the Montagne Noire and Cevennes nappes of the Massif Central; the Moravian nappes of southeastern Bohemia). The "Faille du Midi" of the Franco-Belgian coal basin (the continuation of the Condroz thrust), together with examples from the Alps and Provence, helped Marcel Bertrand to define the concept of overthrusting. The Pyrenees are part of the southern Hercynian domain of the central European cordillera as far as the coal basin of Asturia. This represents the common foredeep of the cordillera and the one that forms the Iberian meseta.

The metamorphosed and granitized core-zone of the Iberian (or Hesperic) cordillera lies northeast of the Iberian meseta and extends from NW to SE. Structures are overturned toward the northeast in the north and toward the southeast in the south.

Considering that Hercynian structures in northwestern Spain describe a Cantabrian curve around the common foredeep of Asturia, and that the Iberian peninsula has undergone displacement to the east accompanied by a southward rotation (thus opening the Bay of Biscay), it is possible that the central European and Hesperic cordilleras once formed a single edifice.

Hercynian Europe was built up in successive phases: the Breton phase (Devonian to Lower Carboniferous), the Sudeten phase (Lower to Middle Carboniferous), the Asturian phase (Middle to Upper Carboniferous), and the Saalian phase (end of Carboniferous). A Palatine phase (Permian to Triassic) is added by some authorities, but it is marked only by the transgression of Triassic deposits over warped and faulted Permian; it constitutes, however, an important phase in the Urals.

Taken together, the first three phases built the main Hercynian structures, whose distribution is common in both the central European and Hesperic cordilleras. The oldest of these - the Breton phase - affected mainly the axes of chains, while the Asturian (the latest) deformed their margins. The Saalian phase corresponds to the late deformation of the Upper Carboniferous intramontane coal basins; this deformation followed the major Hercynian movements.

The Palatine phase is not, strictly speaking, part of the Hercynian. The structural framework of the Permian, with its horst-graben structures and slides, is a harbinger of Alpine Europe. It probably represents the first movements associated with the opening of the Tethys. In later times it continued to control a certain number of the essential tectonic features of Europe, though not always the ones that are most obvious among Alpine structures. The importance of the late Hercynian contribution to the structure of Europe may well be greater than is generally believed.

The extension of the Hercynian orogeny through the rest of Europe takes two forms:

(i) beyond the Hercynian front and in the North Atlantic foreland, a Perihercynian fault field is characterized by a system of horsts and graben best displayed in the Midland Valley of Scotland and its continuation in Ireland, but also found on the other side of the Atlantic - in Newfoundland and Nova Scotia;

(ii) Hercynian deformations are found in the roots of the Alpine chains, including the Pyrenees-Provence complex, throughout the Alpidic branch, and in North Africa.

Alpine Europe

The European Alpine cycle falls into two successive phases: first, the opening of the Tethys from Triassic to Jurassic created the Alpine "geosyncline"; later, the opening of the Atlantic from Cretaceous to Tertiary led to the closing of the Tethys and the formation of Alpine chains. The continent of Europe was subjected to transgressions from two seas - the Tethys and a boreal sea - until the formation of the Atlantic.

There was thus, in both mountain chains and basins, a pre-Atlantic and an Atlantic period. In southern Europe, especially in the Alpine chains, the change from one to the other is at the Jurassic-Cretaceous boundary, while in northern Europe it is even as late as Palaeogene. The end of the Jurassic, however, is an important phase everywhere.

Principal Alpine Complex

The Alpine chains of Europe form two basic complexes. The principal one is linked to the collision of Europe and Africa which closed the Tethys. This complex has opposing vergences: an Alpidic branch on the margin of the European continent and with vergence toward it, runs from Gibraltar to Asia Minor by way of the Betic Cordilleras, the Alps, the Carpathian arc and the Balkans; a Dinaric branch on the margin of the African continent, with vergence toward it, runs from Gibraltar to Asia Minor by way of the North African chains, the Appennines, the Dinarides and the Aegean arc.

The Dinaric branch is strongly folded back on itself in the Italo-Dinaric zone, which is moulded onto a spur of Africa (the Adriatic or Apulian spur, named after the stable platform of southern Italy). Recent Mediterranean history has left this part of Africa isolated on the southern flank of Europe.

The ophiolitic suture, obscure in the northern Mediterranean, becomes clearer in southern Italy (Calabria) and can be

Cortina, northern Italy; the Dolomites in the background are mainly of Triassic limestone. (Photo courtesy E.T. Tozer) followed through the northern Appennines, Dinarides, Hellenides and Asia Minor. It is best developed in the Dinarides and Asia Minor.

In the basic-ultrabasic assemblages, there are *ophiolites*, which correspond to the oceanic crust of the Tethys and are generally of Jurassic age, and *peridotites*, which are the basal crust of continents that bordered the Tethys. Examples include the peridotites at Beni Bouchera, Morocco, and the Lanzo peridotites of northern Italy which, like the African basement that overlies them, are of Precambrian age (600 Ma).

The line of the metamorphic suture is marked by a band of high pressure/low temperature metamorphism of blueschist facies, the first of the kind in the world to be recognized; glaucophane from the Isle of Syros was described in the last century.

Contrasting lithologies in the French Alps: deformed phyllites of Lower Jurassic age in the foreground, with crystalline basement of the Pelvoux Massif behind; viewed from La Grave. (Photo courtesy National Museum of Wales).

The nature of the Tethyan collision was not everywhere the same: mostly it was a direct collision, giving rise only to the formation of nappes of oceanic material. In some places there was hypercollision, such as in the eastern Alps where, following closure of the Tethys, an extensive flat-lying, slicing movement thrust the Italo-Dinaric complex over the ophiolitic suture. Finally, in the few places where collision may not have occurred, there was hypocollision - in the eastern Mediterranean, for example - which explains the formation of the Tyrrhenian and Aegean arcs; here, the still active subduction is that of the remains of the Tethys whose margins have not yet been fused. For the Aegean arc, it seems that this subduction, if not completed, is on the point of being so.

Up to the Carpathians, it is basically Europe that is overthrust even if there is some counter-thrusting toward Africa (the eastern Alps offer the most striking example of this). From the Balkans and Hellenides onwards, it is mainly Africa that is overthrust, even if there is some counter-thrusting toward Europe. The distribution of ophiolites, blue schists and granodiorites of Alpine age illustrates this change which, eastward from the Scutari-Pec transversal, traces the relationships that prevail from southern Eurasia to as far away as Indonesia.

Alpine chains were built up in successive stages: terminal Jurassic (Neokimmerian), middle Cretaceous (Austrian), terminal Cretaceous, terminal Eocene (Pyrenean) and intra-Miocene. These stages fit into a continuous process of deformation in which they mark critical moments. The terminal Jurassic stage marks the beginning of a new phase associated with the opening of the Atlantic; the compression of the Tethys and the general appearance of flysch indicates an island-arc palaeogeography. In easternmost Europe and in northern Asia Minor, the first compressive movements date from the Triassic and Lias on the margins of Eurasia, at the same time as the Tethys was opening up elsewhere.

Pyrenees-Provence Complex

The Pyrenees-Provence complex has the character of an intercontinental chain formed between Europe and Iberia; it resembles a microplate sliding eastward along the north Pyrenean front while undergoing a southward rotation of about 35^{o}. This took place in the Cretaceous and Palaeogene, and accounts for the simultaneous opening of the Bay of Biscay on the west when compressive structures were forming in the east (eastern Pyrenees, Languedoc and Provence). It may even be said that this complex sliding movement deflected the Alpine system and accentuated the curvature of the western Alps.

Thus, the north Pyrenean front appears as a transform fault in a continental environment. Furthermore, it affected the entire lithosphere down to the deepest crust, for mafic fragments of it are squeezed in along the front in the form of Lherzolite massifs (for which the lake of Lherz in the Pyrenees is the type locality).

Torla fold, cored by Cretaceous strata, in the Pyrenees, Spain (looking NW). Mountains in the background are composed of Upper Cretaceous to Lower Eocene strata of the Mont Perdu Nappe overlying Paleocene rocks of the Gavarnie Nappe ("Gavarnie detachment mass"). (Photo courtesy W.C. Morgan)

It was in Provence that Marcel Bertrand (1907) first defined the concept of recumbent folds and overthrusting from studying the Beausset thrust. He compared this with the "Faille du Midi" in the Franco-Belgian coalfield and the double fold of the Glarus in the Swiss Alps, but his original interpretation still stands.

The interior seas (Mediterranean and Black Sea), formed at the expense of the Alpine chain, are associated with a post-Alpine neotectonic fault field of Pliocene to Quaternary age. The boundaries of this field are oblique to the Alpine chain - evident where the southern edge of the eastern Mediterranean protrudes into the Russian Platform. This Mediterranean fault field, developed at the same time as the opening of the Red Sea and the northward shift of the Arabian peninsula, extends over a complex area and appears to give it a unity that is more apparent than real. Only the western Mediterranean is truly an intramontane sea.

Ocean floors do occur in the Mediterranean:

- as an inheritance from the Mesozoic and Tertiary Tethys (the Ionian Sea, for example, and also perhaps the part of the Libyan Sea that adjoins the Aegean arc);
- as a result of the Oligocene extension, which was widespread throughout western Europe and which reached the stage of an oceanic opening in the western Mediterranean: this is the origin of the Algeria-Provence basin, whose links with the fault field of central Europe are obvious; and
- as a product of Pliocene and Quaternary faulting: this was

the case with the Tyrrhenian Sea and will, in the near future, be also true for the Aegean, where neo-oceanic zones are already beginning to appear in the Gulf of Macedonia.

The Mediterranean as an entity, therefore, evolved in Pliocene to Quaternary times, following a Messinian saliferous episode that seems to have been ubiquitous. The Messinian lagoon can be sketched roughly in the outlines of the present Mediterranean, and there are increasing arguments for accepting it as a deep depression below sea level into which the sea broke suddenly during the Pliocene.

Sedimentary Basins

While Alpine history was unfolding, the Mesozoic and Tertiary sedimentary basins spread broadly across Europe, far beyond the front of the Alpine chains. They fall into two categories:

- sedimentary basins corresponding to transgressions of the Tethys or the boreal sea (and later the Atlantic) on to the European platform; and
- basins associated with the central European fault field, extending up to 300 km beyond the Alpine front, and breaking the substrata of the European platform up into horsts that correspond with the Hercynian massifs and graben which form so many sedimentary basins, often of narrow and elongated form.

From the Triassic to Lower Cretaceous times, transgressions moved outward from the Tethys in central and southern Europe. They are demonstrated by the closure of the basins to the west or north, where facies typical of lagoons, lakes and terrestrial environments are found (for example, in the north Pyrenean and Anglo-Paris basins).

In Upper Cretaceous times, the Atlantic opening affected most of Europe and extended to the Arctic in the Eocene. Nevertheless, there were still some basins of Tethyan affinities, such as the Castile and Ebro basins in Spain.

The principal sedimentary basins are, from south to north: the Lusitanian basin, corresponding to Portugal on the western margin of the Iberian Meseta; the New and Old Castile basins and the Ebro basin in Spain, still part of the former Tethys; the Aquitaine and Paris basins in France, whose Tethyan affinities in the Jurassic and Lower Cretaceous are succeeded by Atlantic affinities from the Upper Cretaceous onwards; and the various German basins, in which the same change took place, but only at the very end of the Cretaceous and the beginning of the Tertiary.

In northern Europe, transgressions came from a boreal sea until the opening of the Atlantic in Upper Cretaceous to Palaeogene times. But the distinction between a pre-Atlantic and an Atlantic history is less clear in this region because all transgressions seem to have come from the north or northwest.

The most important basin is that of the North Sea continental shelf, the petroleum potential of which has only recently been recognized. With its general graben form (Viking Graben, Central Graben) and thick Jurassic and Cretaceous sediments, it seems to be linked to an abortive Atlantic (or Arctic) oceanic opening in the Jurassic. This arrangement links up with the central European Graben associated with the Alpine orogeny (the Hague Graben). Thus, the North Sea basins represent a zone of interaction between the evolution of the Atlantic and that of the Alps.

In central Europe, faulting was initiated in Middle to Upper Eocene times and was fully developed in the Oligocene, following the main Alpine collision which took place in upper Eocene time. Faulting may also be related to the reaction of the European basement to this hypercollision, in the same way as the fault field of central Asia is a consequence of the hypercollision of Eurasia with the Indian continent.

The principal element in this fault field is the Rhine-Rhône axis, which cuts through Europe, across the Hercynian chain, to the front of the Alpine chain as far as the western Mediterranean. Here it seems that the opening went so far as to detach the oceanic crust of Oligocene age, but its effects were felt to the west - in the Massif Central whose whole relief is due to these events, and in the Iberian meseta, and to the east - as far as the Harz and the Bohemian quadrilateral, whose form is that of a network of conjugate faults. The vulcanism of central Europe is associated with this fault field; its forerunners appeared in Middle Eocene and continued into late Quaternary, as in the chain of the Puys in the Massif Central.

Summary

The general framework of Europe, then, was built up progressively through successive orogenic cycles. The principal stages in these events (aside from the details of the Precambrian where the palaeogeographic picture is not yet quite clear) include: the common Palaeozoic history of North America and Europe, marking a Euramerican period which created a North Atlantic continent; the Hercynian welding of Europe and Asia creating Eurasia; the opening of the Tethys and the re-welding of Europe to Africa by the Alpine chain - that is, a Eurafrican chapter.

The building of Europe did not call for progressive growth around Precambrian nuclei by the addition of successive chains. On the contrary, each chain was formed from its own oceanic opening, which was no more controlled by the preceding chain than it prepared the way for its successor. In this respect, the building of Europe is a model demonstration of the plate tectonic theory.

Landscapes of Europe: Quaternary Evolution

Glacial Europe

If the landscapes of Europe owe much to their structure (witness the contrast between Alpine peaks and Precambrian shields), many of the most obvious features are linked to very recent history and Quaternary glaciations. In fact, during successive glacial pulses, Europe was covered by three groups of glaciers (Fig. 2).

1. *A vast northern icecap reached as far as London and Amsterdam and beyond Berlin, Kiev and Moscow.* Centred in Scandinavia, particularly around the Baltic from where several glacial pulses pushed moraines to greater or lesser distances up to the limit noted above, this icecap was

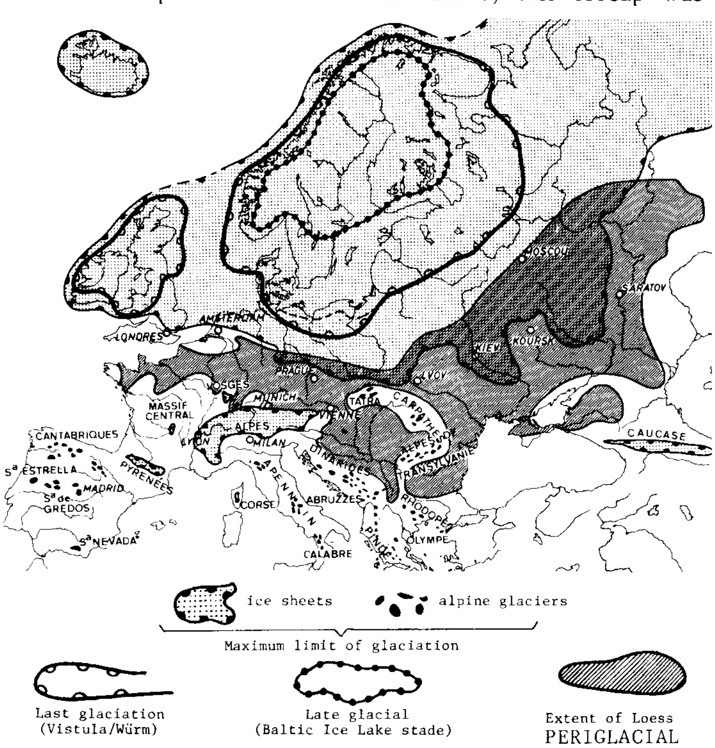

Figure 2. Outline of the Distribution of Quaternary Deposits in Europe

reduced during the last retreat stage (termed late glacial) to a minimum before the present day retreat, with glaciers only in the high ice fields. The two main divisions within this ice-covered region include the centre of the icecap, corresponding to the surroundings of the Baltic Sea (Sweden and Finland), and the area of advance and retreat of glaciers to the limits of their frontal moraines (northern Russia, Poland, northern Germany, and the British Isles).

Two rather different types of landscape resulted:
(i) in the centre of the icecap, in areas strongly eroded by ice, the rocky substratum shows through above bottom moraines; these are landscapes with innumerable lakes;
(ii) in the advance and retreat zone, there are regions with remarkable hydrographic features: proglacial rivers running along the ice front at each retreat stage (Elbe, Oder, Vistula), whose parallelism is thereby explained; lakes are scattered here and there, although most are concentrated at the late glacial front (Vetter, Vernern, Ladoga, Onega).

2. *An Alpine icecap was limited to the Alps proper.* Its front extended in Bavaria as far as Munich, in France to Lyon and beyond, and in Italy almost to Milan. On a smaller scale and allowing for differences of relief, one can see here the same contrast between a high central area occupied by the icecap and areas of intermediate altitude, where glaciers advanced and retreated according to changes in climate. Similar contrasts are found between the high glacial cirques with innumerable little lakes, the glacial valleys so typical of the Alps at intermediate altitudes, and, arranged like a halo all around the Alps - the Swiss, French, Italian, Yugoslavian and Austrian lakes.

3. *Some glaciations were restricted to all the high peaks of Mediterranean Europe.* These were only cirque and valley glaciers, but they have given the Mediterranean mountains a morphology determined by the interplay of altitude and latitude. Even in Peloponnisos, traces of glaciation are found everywhere above 2500 m. Glaciers of the Pyrenees occupy a special place in this group, for they built up a little Pyrenean icecap on the group of peaks of the Cantal and the Mont Dore.

The Lauterbrunnen Valley, Switzerland, viewed to the south-west from Trummelbach. The valley shows the classic features of a glacially eroded area with steep valley sides, a flat floor and high hanging valleys. (Photo courtesy National Museum of Wales)

Periglacial Europe

Periglacial Europe extends beyond the frontal moraines. Features characterizing this region include subdued relief and presence of loess all over central Europe and in a few places in Mediterranean Europe (the Rhone valley, southern Aquitaine). Loess is widespread in Europe and unrelated to bedrock geology or tectonics. Cornice glaciers tended to carve and smooth their hosts and fill valleys with graded screes.

Mediterranean Europe

Most of Mediterranean Europe was untouched by glacial and periglacial influences except for around the edges of the high-altitude glaciers, where there is a periglacial fringe with frost-shattering of the landslips, and the like. But the glacial periods here are represented mainly by pluvial periods in the landscape, with a plant cover typical of the more northern parts of Europe today.

After the last retreat of ice, examples of this flora have been preserved in a few particular situations: an example is the forest of Sainte-Baume near Marseille which retains a northern flora at the foot of a north-facing limestone cliff, giving it a cooler microclimate.

More pronounced reliefs are typical in Mediterranean Europe: cliffs are still cliffs, often steep, especially in limestone country where the east-facing slopes' apparent immunity to erosion is the rule. By combining young reliefs with a climate well suited to their preservation, the Mediterranean is a landscape of the picturesque, heightened by the proximity of the Mediterranean Sea itself.

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THE PRECAMBRIAN IN EUROPE

by

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In Europe, the Precambrian includes rocks as old as 3000 Ma, and most of the global orogenic cycles. This article provides observations on the regional geology, the major features of the Precambrian and the Baltic Shield, and the geological evolution of the Precambrian in Europe, particularly as it relates to uniformitarian theory.

Introduction

An essential feature of the tectonic structure of all continents is that the oldest exposed crust consists of Precambrian platforms. These old stable areas or cratons are surrounded by younger Phanerozoic fold belts.

In Europe, the main area of Precambrian rocks consists of the broad East European or Fennosarmatian Platform, the larger part of which (known as the Russian Plate) is covered by younger unmetamorphosed sediments. Precambrian crystalline rocks in this platform are exposed in the Baltic or Fennoscandian and Ukrainian Shields. The platform is rimmed by younger Phanerozoic fold belts, including Caledonidic, Variscidic and Alpidic orogenic zones (Fig. 1).

In addition to the East European Platform, stable smaller blocks occur around the Barents Sea, in northwestern Britain and in the adjacent regions. The Precambrian of the Barents Platform underlies northeastern Spitzbergen. Metamorphic complexes of the Eria Platform, exposed in northwestern Scotland and the Outer Hebrides, form the western foreland of the Caledonidic belt. Greenland too consists for the most part of Precambrian complexes, which may be correlated with those of the Canadian Shield.

Precambrian rocks are also found within the younger Phanerozoic fold belts. For example, late Precambrian (Eocambrian) rocks are a common component of the Caledonides. Many small massifs or nuclei of Precambrian rocks of different ages occur in the Caledonidic and Variscidic zones, whereas in the Alpidic zone they appear to be rare.

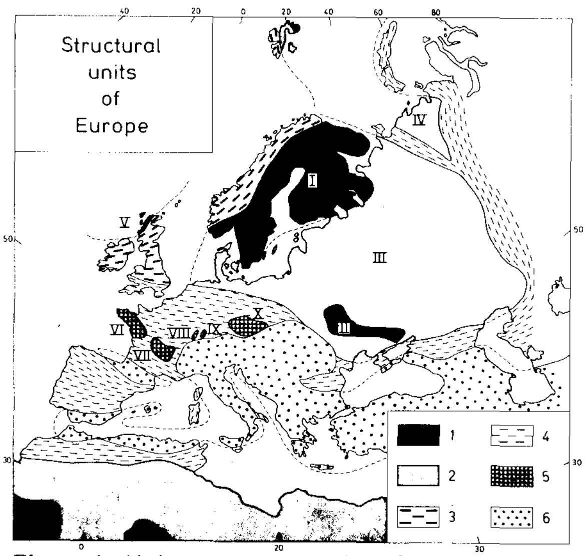


Figure 1. *Major structural units of Europe: 1 - Precambrian metamorphic rocks of shields; 2 - inferred Precambrian shields covered by younger strata; 3 - Caledonian fold belt; 4 - Variscan fold belt; 5 - Massifs in the Variscan zone; 6 - Alpine fold belt. Precambrian units: I - Baltic Shield; II - Ukrainian Shield; III - East European Platform; IV - Barents Platform; V - Eria Platform; VI - Armorican Massif; VII - Massif Central; VIII - Vosges; IX - Black Forest; X - Bohemian Massif.*

Precambrian Platforms

East European Platform

The broad East European Platform, the basement of which consists of Precambrian metamorphic complexes, extends across Denmark, part of Norway and Sweden, Finland, the north of Germany, northern and eastern Poland, and most of the Soviet Union's European part (Fig.1). Different proposals regarding the position of the platform's southwestern border have been made (Fig. 2), some suggesting that the platform extends as far as central England, where small inliers of Precambrian metamorphic rocks have been identified.

The platform is exposed in the Baltic and Ukrainian Shields, but the largest part of it - the Russian Plate - is overlain by a thick cover of unmetamorphosed sedimentary rocks.

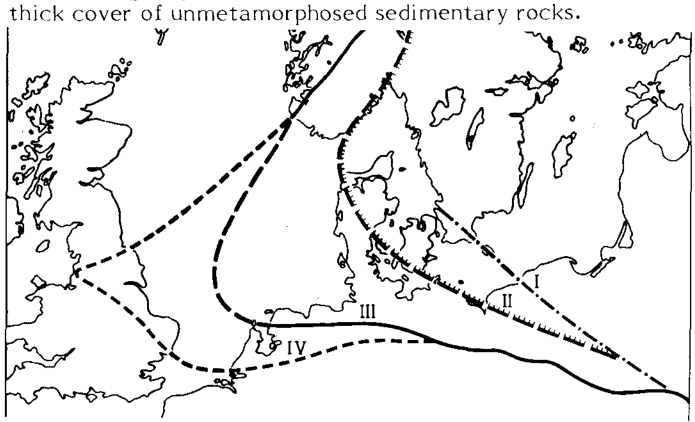


Figure 2. *Suggested position of the southwestern border of the East European Platform: I - Törnquist line (1910); II - H. Stille (1924); III - The tectonic map of Europe (1960); IV - E. Bailey (1928).*

The Baltic Shield

The Baltic or Fennoscandian Shield, the broadest shield area on the European continent, is an uplifted part of the East European Platform whose boundaries and main structural features dip gently under the platform's sedimentary cover. Broad areas of early Precambrian (Archean) basement gneisses are exposed in the east - the oldest part of the Shield (Fig. 3). The Belomoridic gneiss belt and the granulite arch of Lapland represent high-grade metamorphic parts of this basement complex, which became intensively reworked and recrystallized during the younger Svecokarelidic orogeny. The ages of the basement gneisses are usually 2600-2800 Ma, although older ages (ranging from 3000 to 3500 Ma) have been recorded, especially in the Kola Peninsula.

An old basement complex of unknown age, thoroughly reworked by Dalslandian movements about 1000 Ma ago, occurs in the southwestern part of the Shield. Some authors have correlated it with the basement in the eastern part of the Baltic Shield. In northern Finland (about 2400 Ma ago) basement gneisses were penetrated by mafic igneous intrusions which formed layered sheet- or lopolith-like bodies.

The main part of the Baltic Shield belongs to the Svecokarelidic fold belt which exhibits many features similar to younger orogenic belts. The early Precambrian basement

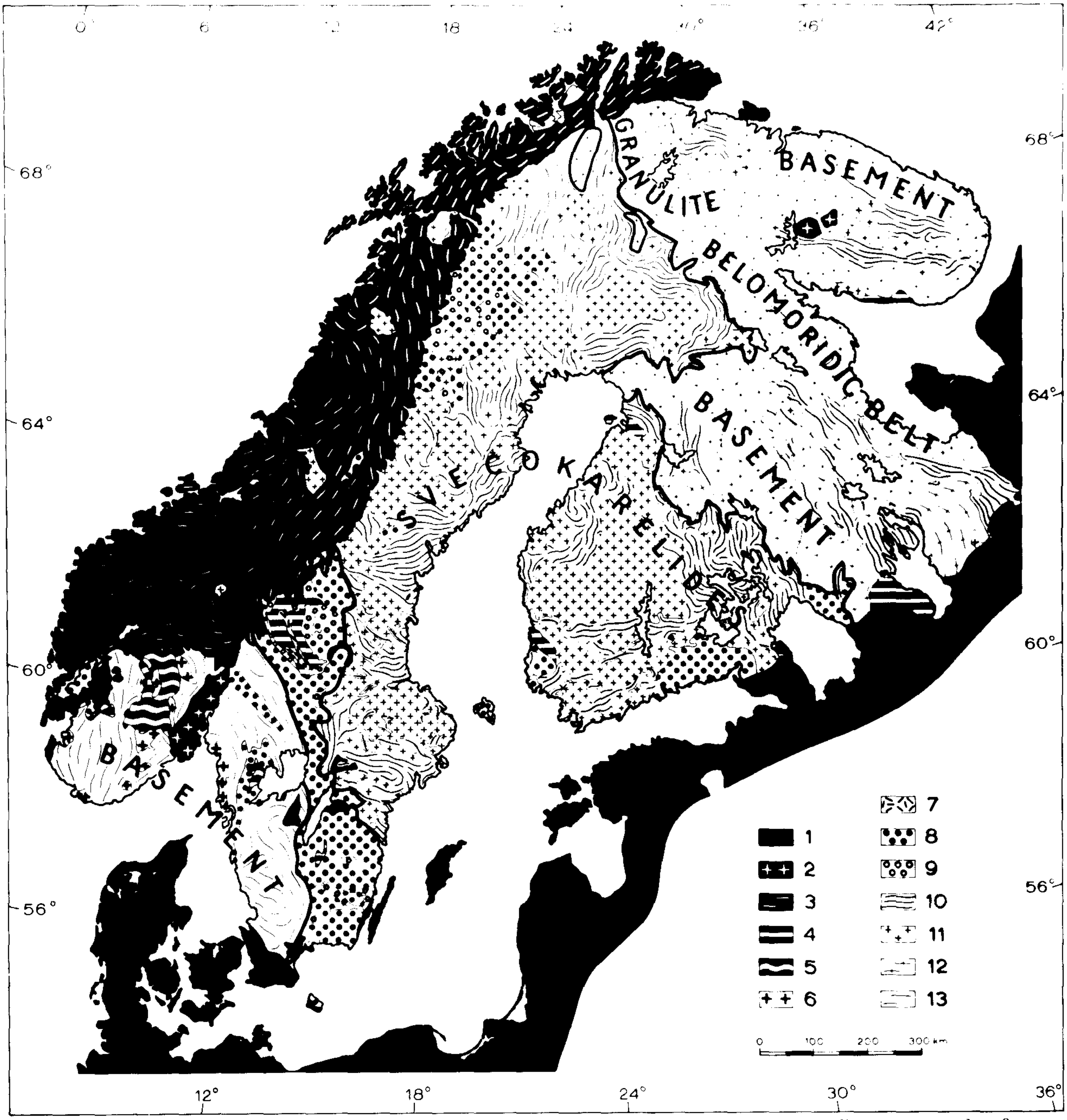


Figure 3. *Main structural units of the Baltic Shield: 1 - Paleozoic and younger sedimentary rocks; 2 - Paleozoic igneous rocks; 3 - Caledonides. 4 - Precambrian unmetamorphosed sedimentary rocks; Jotnian formations. 5 - Dalslandian fold belt; gently folded Dalslandian formations; 6 - Dalslandian granites; 7, 8, 9 - Precambrian igneous rocks, representing the period of cratonization following the Svecokarelidic orogeny; 7 - diabases; 8 - Gothian granites and rapakivi granites; 9 - volcanic rocks; 10, 11 - Svecokarelidic fold zones; 10 - schists and gneisses; 11 - plutonic rocks; 12, 13 - Basement complexes; 12 - Presvecokarelidic basement; 13 - basement of unknown age.*

was deeply eroded and peneplained about 2300 Ma ago, forming the so-called Jatulian continent; on it and along its border, sedimentation of the transgressive Jatulian group (basal beds, quartzites, dolomites and sapropelic pelites) took place some 2300-2000 Ma ago. This sedimentation was accompanied by lively mafic volcanism which occurred in phases 2200-2000 Ma ago.

Geosynclinal basins then developed west of the Jatulian continent and thick geosynclinal deposits accumulated, the associated volcanism (1920-1880 Ma) being only slightly older than the orogenic plutonism of the Svecokarelides. These deposits were metamorphosed into crystalline schists during the Svecokarelidic orogeny about 1900-1800 Ma ago, accompanied by the emplacement of enormous masses of granitoids.

The Svecokarelidic orogeny was followed by a long period of erosion and cratonization. Vertical block movements took place and large volumes of diabase, granite and associated volcanic rocks were intruded in many pulses into the stable platform about 1700-1550 Ma ago; these intrusions included the rapakivi granites, the Gothian granites in Sweden and their volcanic equivalents.

The Jotnian red beds, arkoses, and siltstones, were deposited about 1400-1300 Ma ago upon the deeply eroded Precambrian surface to form the oldest nonmetamorphic sedimentary cover of the Baltic Shield. Diabase dikes and sills occur abundantly in many Jotnian deposits, and they represent hypabyssal eruption channels for basaltic magma intrusions into the stable platform.

The so-called Dalslandian, or Sveco-Norwegian tectonic movements took place about 1000 Ma ago in the southwestern corner of the Baltic Shield. Dalslandian formations, deposited upon an old basement of unknown age, are of the platform type; no geosynclinal strata are present. The formations underwent gentle folding accompanied by intrusions of granites and pegmatites. These tectonic movements caused a regional rejuvenation of the ancient basement in the southwestern corner of the Baltic Shield.

The youngest Precambrian of Scandinavia consists of so-called Eocambrian sediments, deposited on the Shield along what is now the eastern margin of the Caledonides.

The Ukrainian Shield

Five megacycles subdivide the Precambrian of the Ukraine:

		Ma
Precambrian	I	3500 - 2600
"-"	II	2600 - 1900
"-"	III	1900 - 1600
"-"	IV	1600 - 1100
"-"	V	< 1100

The Ukrainian Shield is composed mainly of megacycles I to IV, with Riphean platform sediments (Precambrian V) overlying the western boundary of the Shield and demonstrating that the folding and metamorphism of the Shield originated in pre-Riphean times. The geological evolution of the Precambrian in the Ukrainian Shield is similar to that of the Baltic Shield.

Basement of the Russian Plate

The basement under the thick sedimentary cover of the East European Platform has been studied thoroughly by Soviet and Polish geologists. The basement surface occurs at depths which vary from a few hundred meters to 1-2 km above the uplifts (anteclises) and up to 3-4 km in the depressions (syneclises). The structure of the basement is characterized by faults with great vertical displacements measuring up to many kilometers, narrow graben-like depressions (aulacogens) as deep as 10 km, and well defined horsts.

The basement consists of metamorphic and plutonic rock complexes of pre-Riphean age related to those in the Baltic and Ukrainian Shields, while the cover comprises Late Precambrian (Riphean), Paleozoic, Mesozoic and Cenozoic formations.

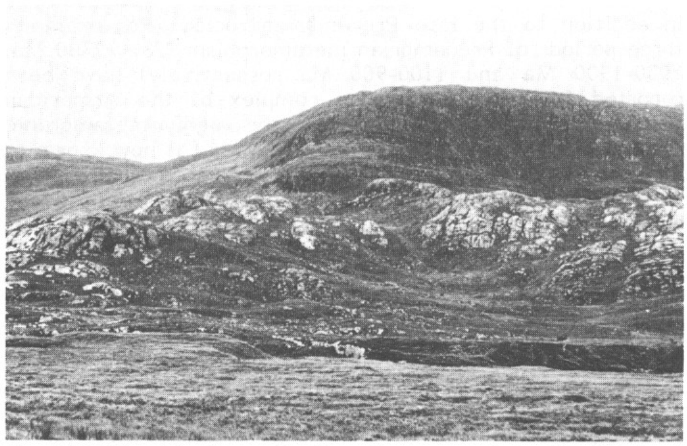
Barents Platform

An old platform whose extent is still unknown occurs in the area of the Barents Shelf. It seems to have formed one foreland of the Caledonides on the platform's western side. The southern corner of this fragmentary platform is rimmed by the Assyntian fold belt of Kanin-Timan and by the Variscan Novaya Zemlya zone; the northern boundary is unknown. Basement rocks are exposed only in northeastern Spitzbergen.

Eria Platform

This old platform with unknown boundaries is exposed in northwestern Scotland and the adjacent regions. Here the crust is composed of Precambrian (Lewisian) metamorphic complexes, overlain discordantly by Late Precambrian (Torridonian) and Cambrian sediments.

The fragmentary Eria Platform forms the northwestern foreland of the British Caledonides. The basement consists of Lewisian gneisses, schists and igneous rocks which represent at least two metamorphic complexes of different ages. An older Scourian complex was metamorphosed about 2400-2600 Ma ago, while a younger Laxfordian complex was folded and metamorphosed ~1600 Ma ago, causing rejuvenation of the older rocks. The Late Precambrian, unmetamorphosed Torridonian sediments were deposited about 1000-650 Ma ago, and consist mainly of molasse-type terrestrial arkose sandstones which form a cover up to 6 km in thickness over the Lewisian complex.



Lewisian/Torridonian unconformity exposed to the south of Loch Torridon, Northwest Scotland. The undulating erosional surface can be clearly identified. (Photo courtesy National Museum of Wales).

Greenland Platform

The Precambrian of Greenland can be regarded as the most eastern extension of the Canadian Shield, and is briefly mentioned here because the 26th International Geological Congress plans to include some excursions to this largest island in the world. Areas of folded Precambrian underlie the greater part of Greenland, covered mostly by glaciers. Precambrian rocks, however, are well exposed in the ice-free coastal areas of West, South and Southeast Greenland. The Greenlandic Shield is bordered by areas of folded Paleozoic strata to the north and east of the island.

The Precambrian includes folded strata of Archean and Proterozoic ages as well as anorthosite, gabbro and rapakivi granite intrusions (~1600-1700 Ma) belonging to the so-called Sanerutian complex. The Gardar group of southern Greenland (<1400 Ma) is composed of sandstones and red quartzites with basaltic lavas, and overlies the Ketelidian and Sanerutian complexes.

Precambrian in Phanerozoic Folded Areas

Late Precambrian (Eocambrian) deposits are part of strata deformed by Caledonidic movements in Spitzbergen, Scandinavia and Great Britain. For example, a major part of the Hecla Hoek geosynclinal succession in Spitzbergen, the psammites of the Sparagmitian in Scandinavia and the Moinian in Scotland, are all of Late Precambrian age. The upper part of the Late Precambrian strata contains glacial-boulder beds and tillites which are important key units for stratigraphical correlation.

Precambrian metamorphic and plutonic rocks of different ages occur as many windows, especially in the Caledonidic belt of Scandinavia. The rocks in autochthonous windows are correlated with those of the Baltic Shield. By contrast, the Precambrian rocks involved in the Caledonidic metamorphism have been so thoroughly reworked and rejuvenated that correlation with Precambrian strata is commonly difficult.

In a zone trending from southern Great Britain and western France as far east as Czechoslovakia, many massifs in areas of folded Variscan or Hercynian strata are Precambrian. They include the well-known Armorican Massif, Central Massif, Vosges, Black Forest and the Bohemian Massif (Fig. 1). Relicts of Precambrian occur also in the Variscan zone of Portugal and Spain.

Most Precambrian rocks of the Variscan zone are considered to be Late Precambrian. Tillites characteristic of the upper part of the Eocambrian reported in these strata support this age assignment. The rocks are polymetamorphic with evidence of Assyntian, Caledonian and Variscan folding and metamorphism. They too have been so intensively reworked by the effects of Variscan folding, plutonism and polymetamorphism, that in many instances it is difficult to determine their original age even with radiometric methods.

Remnants of older Precambrian appear in the Variscan zone in addition to the late Precambrian rocks. For example, three periods of Precambrian metamorphism (2800-2700 Ma, 2000-1900 Ma and 1100-900 Ma respectively) have been reported from the Pentevrian complex of the Armorican Massif of France. Furthermore, the highly metamorphic Moldanubian nucleus of the Bohemian Massif is now known to include Precambrian rocks older than the low-grade metamorphic Late Precambrian ones of Assyntian, which border the nucleus.

Some relicts of Precambrian rocks have also been reported from different parts of the Alpidic zone. These have commonly been subjected to Assyntian or Variscan metamorphism and reworked during Alpidic folding. Again, the Precambrian age of many of these polymetamorphic rocks is difficult to determine with certainty.

Acid and gneissic Precambrian plutonic rock forming part of a Caledonian thrust sheet NW of Rödal, Norway. (Photo courtesy W.H. Poole)

Evolution of the Precambrian

At the end of the nineteenth century, great progress was made in studies of the early history of the Earth when the actualistic or uniformitarian theories proved applicable to the study of metamorphic Precambrian complexes. For example, Precambrian crystalline schists display many sedimentary and volcanic features, which indicates that their deposition took place under conditions similar to those prevailing at present.

Geological events during a period of about 3000 Ma are recorded in the Precambrian and Phanerozoic of Europe. Intensive geological studies of Precambrian tracts in different continents, complemented by age determinations, show that the tectono-plutonic orogenic events in that era took place periodically and simultaneously in wide areas of different continents. These new data have been used for the compilation of international geological, tectonic, and metamorphic maps of the continents.

Most worldwide orogenic cycles are also represented in Europe. For example:

	Ma
Katarchean (Saamian)	> 3300
Presvecokarelidic	~ 2800 - 2600
Svecokarelidic	~ 1900 - 1800
Dalslandian (Grenville)	~ 1000
Assyntian (Baikalian)	~ 550
Caledonian	450 - 400
Variscan (Hercynian)	340 - 240
Alpine	< 85

These orogenic cycles with their approximate ages suggest that the orogenic pulses have been more frequent in the Phanerozoic than in Precambrian times.

Precambrian platforms played an important role during the evolution of the younger orogenic zones by controlling the position of the thick, broad zones of late Precambrian geosynclinal deposits around the cratons, which were later subjected to folding and/or metamorphism during the Assyntian, Caledonian and Variscan orogenies. The occurrence of a coherent Assyntian fold belt in Western Europe is still disputed, though many relicts of Assyntian deformation have been found.

The oldest Archean fold belts contain greater relative volumes of volcanic and plutonic rocks than the younger belts, possibly because the ancient crust was rather thin and not differentiated into the platforms and geosynclines which later acted as major structural elements controlling crustal evolution from Proterozoic time onwards.

Some Archean and Early Proterozoic rocks (for example - quartz-banded iron ores, lazurite deposits) suggest that their sedimentation took place in the absence or deficiency of oxygen in a primitive atmosphere. Red beds, typical representatives of sediments deposited in an oxidizing environment, are widespread among the Proterozoic rocks deposited after the Svecokarelidic orogeny (the Jotnian sediments, 1300-1400 Ma old, serve as an example).

Archean carbonaceous black schists suggest the existence of primitive organisms during earliest geological times. The first organisms were probably algae capable of living in many kinds of extreme environments, including anaerobic ones. Organic remains are very rare in the Early Precambrian rocks, but stromatolites do occur in the Proterozoic and are abundant in the Late Precambrian. Documentary evidence of metazoa also exists.

Precambrian complexes contain some rock types that are characteristic of certain phases of crustal evolution. For example, quartz-banded iron formations are characteristic of the Archean greenstone belts, while rapakivi granites, with associated anorthosites and volcanic rocks, seem to be peculiar to the crustal evolution of the Middle Precambrian (1700-1500 Ma ago).

Most of the Precambrian is metamorphic and displays varying grades of metamorphism. Amphibolite facies are common and widespread. Granulite facies rocks occur in some places in Archean terrain, and greenschist facies are common in the Late Precambrian. Metamorphic zoning of Precambrian areas does not seem to be as distinct as in younger orogenic belts, and mineral associations representing relatively high pressure/low temperature are rare.

Deeply eroded roots of Precambrian orogenic zones have provided a key for investigations of the composition of the Earth's crust and of the many transformation processes that have taken place in the depths of the Earth. Geological studies of the Precambrian areas in Europe have yielded abundant material for petrogenetic studies, which have proved fruitful in developing the petrology of metamorphic and plutonic rocks. The concepts of mineral facies classification, metamorphic differentiation and remelting (anatexis) of rocks developed through investigations of the Precambrian. Furthermore, the study of the Precambrian, so rich in granites and migmatites, brought the global problem of the origin of granites and the processes involved in cratonization into the forum of lively scientific discussion.

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CALEDONIAN EUROPE

by

B.A. Sturt, N.J. Soper, P.M. Bruck and F.W. Dunning

The North Atlantic Caledonides were broken up by continental drift or isolated by epeirogenic movements into several fragments in post-Devonian time. In the following series of articles, four of these fragments are described according to geotectonic premise, reconstructing concisely the sequence of structural and metamorphic events which formed the Caledonides in Ordovician and Silurian times.

Introduction

During the Upper Proterozoic (mainly Upper Riphean and Vendian time), a belt of sedimentation extended along the margin of the Laurentian continental plate, following the opening of the Iapetus Ocean. On the opposite side of the ocean, late-Precambrian (Cadomian) disturbances folded and block-faulted the equivalent sedimentary and volcanic rocks marginal to the Fennoscandian continent. In the Cambrian, a new belt of sedimentation and volcanic activity encroached on the eroded Cadomian fold-belt, while sedimentation persisted on the Laurentian shore of Iapetus.

Around the end of the Cambrian, the northern Laurentian belt underwent very intense alpinotype deformation and metamorphism - the Grampian orogeny - probably as a result of microcontinental collisions. Sedimentation continued elsewhere with relatively little interruption until the Silurian, when the continental collision between Laurentia and North Europe (already presaged by the merging of faunas in the late Ordovician) folded the Lower Palaeozoic sequences and, in a major outbreak of magmatism and vulcanism, brought the North Atlantic Caledonides into existence.

The Caledonides were subsequently broken up by continental drift or isolated by epeirogenic sinking into five separate fragments: East Greenland, Svalbard, Scandinavia, the British Isles and Newfoundland (Fig. 1). For geotectonic reasons, the alpino-type metamorphic Caledonides of Scotland, Ireland and Scandinavia are described as a unit (though they are not equivalent in age), followed by the non-metamorphic mediotype late Caledonides of Britain and Ireland, the Caledonides of Greenland and Svalbard, essential to the understanding of the North Atlantic Caledonides, and lastly, the enigmatic and problematic Caledonides of central Europe, which fit with the greatest difficulty into plate tectonic syntheses, and whose relationship to the North Atlantic Caledonides is obscure. Newfoundland is omitted purely for reasons of space.

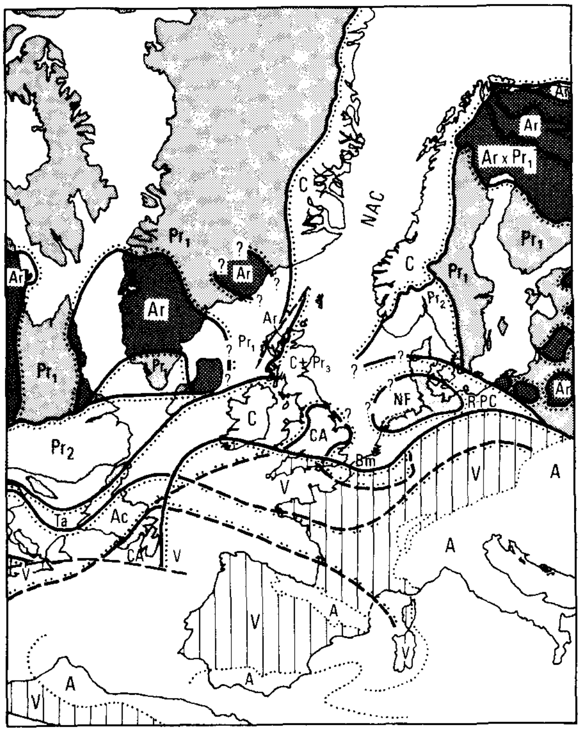

Figure 1. *Orogenic zones in North Atlantic region on a pre-Atlantic reconstruction. Dots are located on younger sides of boundaries of orogenic zones; the latter are broken where overlapped by younger belts. The track of the future Alpine zone is shown. Ar - Archaean, Pr_1 - Early Proterozoic (Svecofenno-Karelidic, Hudsonian, Nagssugtoqidian, Laxfordian) orogenic zones, Pr_2 - mid to late Proterozoic (Grenvillian, Sveco-Norwegian, Dalslandian) orogenic zones, Pr_3 - Late Proterozoic (Morarian) orogenic zone in the Scottish Caledonides, CA - Cadomian-Avalonian orogenic zone, C - Caledonian, NAC - North Atlantic Caledonides, Ta - Taconic belt, Ac - Acadian belt, R-PC - Rügen-Pomeranian Caledonides, NF - Norddeutsches Festland (median massif), Bm - Brabant massif, V - Variscan/Hercynian/Appalachian orogenic zones, A - Alpine zone.*

Orthotectonic Caledonides of the British Isles and Scandinavia

by

Brian A. Sturt

The Caledonian metamorphic rocks of Scandinavia and the British Isles form the orthotectonic section of the northeastern European Caledonides. Though separated only by the North Sea, they show interesting and fundamental differences in character and evolution. In recent years, our understanding of large segments of this orthotectonic section has been augmented by various studies, many of which are summarized in Tozer and Schenk (1978).

The traditional view was that the Moine thrust belt of Scotland and the Scandinavian thrust-front represented respectively the northwestern and southeastern margins of the Caledonian orogenic belt. However, it is now thought that the major translations on the Moine Thrust took place in early to middle Ordovician times, whereas along most of the Scandinavian thrust-front, translation of nappes took place in late Silurian to earliest Devonian times.

The Moine Thrust represents the frontal thrust translations related to the Grampian orogenic phase (late Cambrian/early Ordovician) which can be correlated in time with the Finnmarkian (Sturt et al., 1978) of northern Norway. In both the Grampian and Finnmarkian, the major movements appear to have been in the early Ordovician, though later reactivation probably occurred in both cases.

It is now known that the development of the Caledonian orthotectonic zone in Britain and Ireland was essentially

View toward north shore of Loch Glencoul showing part of the Caledonian Moine thrust zone. From left to right Lewisian gneiss (metamorphosed between 2800-2700 Ma), bedded Cambrian quartzites, the Glencoul Thrust overlain by Lewisian. The Moine Thrust is thought to have developed in four phases between post Cambrian and early Devonian times, with major translations in early to middle Ordovician time. (Photo courtesy W.C. Morgan).

completed during the Grampian. This is in marked contrast to the Scandinavian orthotectonic zone, where the structural/metamorphic development occurred in two distinct cycles: the Finnmarkian and the Main Scandinavian (late Silurian). Thus the two segments had different geotectonic evolutionary patterns, particularly during post-Finnmarkian/Grampian development.

The British Isles' Segment

This orthotectonic segment represents the heartland of Caledonia, where many concepts concerning Caledonian orogenic evolution were formulated, based on studies made in "classic" terrains. In recent years, however, new discoveries and re-assessments, focussing on internal relationships and possible tectonic evolutionary models, have been made which will eventually lead to a major revision of the significance of this orthotectonic segment.

The orthotectonic belt of Britain and Ireland has a clearly defined NNE/SSW trending thrust-front and consists essentially of two major lithostratigraphic units referred to as the Moine (best developed NW of the Great Glen fault, Scotland) and the Dalradian (SE of the fault: see Fig. 2).

Figure 2. Caledonides of the British Isles.

The Moine, long regarded as a sub-Dalradian continental prism sequence of Late Precambrian age, and probably the time-equivalent of the Torridonian clastic sequence of the foreland, is now known to be an extremely complex tectono-stratigraphic unit. In addition to the long-recognized "Lewisian inliers", the Moine is now considered to contain at least two major sequences which display different patterns of orogenic development. Evidence indicates widespread presence of metasediments and gneisses, initially deformed and metamorphosed during the Grenville Orogeny around 1000-1100 Ma ago.

Some have also claimed the existence of a later Precambrian orogenic phase (the Morarian) at around 700-800 Ma ago, though evidence for this is more tenuous (van Breeman et al., 1978). Rocks unaffected by these events (that is, the younger Moines or Grampian Group), are now considered to be a cover sequence to older metamorphic rocks, passing vertically upwards into the more varied shallow-water sequence of the Dalradian.

Glencoul Thrust of the Moine thrust zone showing Lewisian gneiss of Archean age, separated from the underlying Cambrian (Durness) limestone by a mylonite zone. (Photo courtesy W.C. Morgan)

In early plate-tectonic models, the Dalradian, which spans the Precambrian-Cambrian boundary and possibly extends into the lowermost Ordovician, was regarded as a continental rise prism built out from the edge of a developing Atlantic-type continental margin onto oceanic crust to the south (Dewey and Pankhurst, 1970). This is now considered unlikely, since sediments of the Upper Dalradian require a provenance area in continental crust lying to the south of the depositional basin (Harris et al., 1978).

The latter postulate has been enhanced by the discovery of high-grade basement-type metamorphics as inclusions in the Carboniferous volcanic vents of the Midland Valley of Scotland and in Central Ireland, and by evidence from the LISPB seismic experiment (Bamford et al., 1977), where the presence of high-velocity continental crust can be inferred at fairly shallow levels beneath the Midland Valley. An important recent article (Harris et al., 1978) interprets Dalradian sedimentation as having occurred in an ensialic, fault-controlled marginal basin; sedimentation has been analyzed as a record of several large-scale, basin-deepening and shallowing sequences which indicate a progressive upward increase in tectonic instability.

Metamorphism affecting the Dalradian is essentially of the classical Barrovian type, with a local development in NE Scotland of lower pressure Buchan type metamorphism. The age of metamorphism and attendant deformation is generally placed in earliest Ordovician times, based on a plethora of radiometric age determinations. Williams (1978), however, points to a number of possible ambiguities in this interpretation, while Phillips et al. (1976) suggest that deformation may have been diachronous.

The structure of the Dalradian of Scotland and Ireland is dominated by alpino-type nappe tectonics with associated thrusts. In a recent proposal, the rocks of the Banff Division of NE Scotland are regarded as part of a major thrust nappe separated from the main Dalradian by Precambrian gneisses (Ramsay and Sturt, 1979). That the internal relations in the Dalradian are not simple is indicated by the recognition of Precambrian gneiss units within the sequence - in NW Mayo (Max and Sonet, 1979), the Ox Mountains (Pankhurst et al., 1976) and NE Scotland (Ramsay and Sturt, 1979).

Various attempts have been made to fit the orthotectonic segment of the British Isles into a general geotectonic evolutionary model which embraces also the paratectonic zone (as, for example, by Phillips et al., 1976). There are still many uncertainties in such reconstructions, some of which will only be resolved when palaeomagnetic data, showing a reasonably precise positioning for the British Isles during the Lower Palaeozoic, are available.

The Scandinavian Segment

The Scandinavian Caledonides have a clearly defined south-eastern foreland, with a thin autochthonous sedimentary sequence overlying the crystalline rocks of the Baltic Shield. This sequence is generally of Late Precambrian to Cambrian age, extending locally upwards into the Upper Ordovician in Central Jämtland.

The orthotectonic section of Scandinavia is dominated by extensive nappes thrust great distances, probably in excess of 600 km (Gee, 1978). Large basement windows are exposed in a series of great culminations arching the nappe piles. It has been shown (in Tozer and Schenk, 1978) that the nappe sequences are complex, and contain, in addition to Caledonian metamorphics, Precambrian sialic gneisses and probably metasediments as well. In addition, it was recently established that considerable fragments of obducted oceanic crust in the form of ophiolites occur within the nappe sequence (Furnes et al., 1979).

Folding in Silurian sandstones and quartzites, Rannasen, Jämtland, central Sweden. (Photo courtesy National Museum of Wales).

The orthotectonic evolution of the Scandinavian Caledonides occurred in two major orogenic cycles: the Finnmarkian and the Main Scandinavian. The Finnmarkian has its type area in northernmost Norway (Sturt et al., 1978) where it impinges directly on the autochthon and is truncated by later nappes belonging to the Main Scandinavian cycle. It involved the emplacement of a series of nappes containing distinctive basement-cover couplets. Orogenic metamorphism was entirely of the medium pressure Barrovian type, with a general increase in grade upwards through the nappe pile; it took place during Late Cambrian and Early Ordovician times. Basement gneiss shows evidence of variable degrees of Caledonian reworking, although local stratigraphic unconformities with the overlying Caledonian sediments are preserved.

The highly unusual synorogenic magmatism of the Seiland Province is found in West Finnmark and includes a large number of layered gabbro plutons (derived from varied parent magmas), ultramafic plutons and alkaline complexes. The Finnmarkian complex is truncated by nappes of the Main Scandinavian phase in the Lyngen district (Zwaan and Roberts, 1979); further south it was incorporated as a basement element during the Main Scandinavian cycle.

Recent interpretations suggest that there was extensive involvement of oceanic crust in the framework of the Scandinavian Caledonides (Furnes et al., 1979). Large fragments of what is probably oceanic crust are located along the western part of Scandinavia from Karmoy in the south to the Lyngen peninsula in the north. These include the virtually complete ophiolites of Karmoy (Sturt et al., 1979) and Leka (Prestvik, 1979), and a large number of less complete fragments. Stratigraphic evidence from the Storen Ophiolite of the Trondheim region suggests that ophiolite obduction occurred in pre-Middle Arenig time, though, with lack of faunal control, the obduction of other fragments cannot be dated more precisely than sometime prior to the Middle/Upper Ordovician.

The implications of this are profound and point to major ophiolite obduction being more or less contemporaneous with the thrusting, folding and metamorphism of the Finnmarkian continental prism. This pattern appears to correlate well with the major ophiolite obduction in western Newfoundland and the deformation and metamorphism of the Fleur de Lys continental prism (Williams, 1978).

A significant feature in the western part of the orthotectonic zone is the widespread evidence for a major tectono-metamorphic hiatus marked by uplift, deep-seated erosion and deposition of transgressive continental or shallow marine deposits in the Ordovician. Except for parts of the Trondheim region, there is no precise stratigraphic evidence for dating the hiatus more accurately than Pre-Upper Ordovician, and the need for obtaining precise stratigraphic data for the transgression in different regions is obvious.

Following Finnmarkian orogenesis and ophiolite obduction, erosion products accumulated in continental and shallow water marine deposits, and in thick, deep-marine infill of major sedimentary basins. The evolution of the volcanic island arc and marginal back-arc basin (which developed in early to mid-Ordovician times in Iapetus), is particularly well illustrated in the Trondheim region (Furnes et al., 1979). No clear evidence is yet available to indicate ophiolite obduction during the Main Scandinavian orogenic phase.

The major thrusting, accounting for the present-day distribution of the major post-Finnmarkian nappes, occurred mainly in late Silurian time, though evidence suggests that it continued through into post-Lludlow or even post-Downtonian times (Gee, 1978). Metamorphism is again essentially of the medium pressure Barrovian type with local areas of low pressure Abukuma type occurring in the southern part of the Trondheim region (Guezou, 1977). The timing of the peak of orogenic metamorphism, based on reasonable stratigraphic and geochronological control, is Wenlockian in age and essentially prior to final nappe emplacement.

One of the great unresolved problems regarding nappes of the Main Scandinavian lies in identifying the provenance of great crystalline sheets high in the nappe sequence in southwestern Norway, such as the Jotunheim and Hardanger-Ryfylke nappe systems. This is of obvious importance to formulation of an evolutionary geotectonic model, especially when it has been shown that nappe units high in sequence in the East Greenland Caledonides bear similar high grade Precambrian gneisses (Higgins, 1976).

Lower Ordovician Venna volcanic conglomerate with intercalated volcanics, Hölanda area, Norway. (Photo courtesy W.H. Poole)

Comparing the Segments

Looking at the differences in the evolutionary pattern of the British/Irish and the Scandinavian orthotectonic belts, one notes the similarity of timing of the Grampian and Finnmarkian orogenic episodes. The Dalradian, however, was deposited in a marginal basin, whereas the time equivalent sequences of Scandinavia developed as a continental prism along the margin of a major ocean, followed by substantial obduction of oceanic crust onto the Scandinavian margin in early Ordovician times.

During the Ordovician, the metamorphic Caledonides of Britain and Ireland ceased to be an orthotectonic belt; subsequent tectonics were dominated by vertical uplift. In the western part of the Scandinavian orthotectonic belt, major transgression occurred in the Ordovician and new basinal sequences were deposited on the eroded relics of the Finnmarkian belt, with evidence for island arc development and back arc spreading.

The orogenic activity of the Main Scandinavian phase with its extensive southeasterly nappe translations, folding and metamorphism and local basement reactivation is not represented in the orthotectonic belt of Britain/Ireland. This leads one to point to the enigmatic position of Caledonian nappe sequences of Shetland, which lies north of the British orthotectonic zone. Shetland includes, in part, a sequence of nappes containing a possible major ophiolite slab which Flinn (1959) has likened to the Bergen-Jotun section. It is of interest also that these crucial relations in Shetland have been ignored in almost all geotectonic reconstructions for both the British Isles and Scandinavia, and represent an important area for further study.

Considerable work must be done before meaningful models can be formulated to successfully integrate the patterns of geotectonic evolution of the NE Atlantic Caledonides. There is need for carefully designed paleomagnetic studies to enable precise palaeogeographic positioning of the various segments of the British Isles and Scandinavia during Lower Palaeozoic evolution.

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Non-Metamorphic Caledonides of Great Britain

by

N.J. Soper

As outlined below, six geotectonic zones of general NE trend can be recognized in the paratectonic Caledonides of Britain (Fig. 2).

Midland Valley

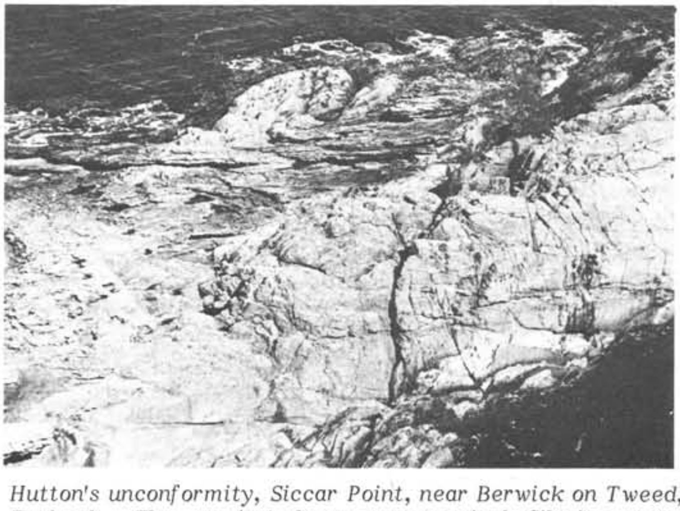
This is a post-Caledonian graben bounded to the NW by the Highland Border Fault which is traditionally taken as the southern limit of the orthotectonic Caledonides. Recent deep seismic investigations (Bamford et al., 1978) and studies of basement xenolith suites in Carboniferous volcanic necks (Graham and Upton, 1978), have shown that Lewisian-type basement of granulite-facies exists beneath the Midland Valley and possibly represents the southward Lewisian extension of the Hebridean Craton. The basement is probably overlain by a southerly thinning wedge of low grade but intensely deformed Dalradian metasediments, mantled by a weakly deformed cover of mainly marine Silurian and continental early Devonian clastics.

The Southern Uplands Fault is the southern boundary of this graben; most exposures are late Palaeozoic (Devonian, Carboniferous and Permian), although small outcrops of Ordovician and Silurian shale and graywacke occur close to the southern boundary. In addition, there are exposures of the early Ordovician ophiolite-amphibolite-olistostrome complex (at Ballantrae near Girvan), disrupted by NW-directed thrusting which figures prominently in plate tectonic reconstructions of the Caledonides.

Southern Uplands

This area is inferred to be underlain by continental basement, nowhere exposed but characterized by seismic velocities more representative of the 'Pentevrian-type' deep basement of northern England than of the Lewisian-type basement to the north. The exposed cover consists of late Ordovician-early Silurian deep water (perhaps oceanic) Moffat Shales overlain by thick Silurian flysch.

Recent structural re-interpretation of the area between the Southern Uplands Fault and the Ettrick Valley Fault (Weir, 1979) indicates imbricate stacking of the cover sequence on a series of listric faults, propagated sequentially towards the SE during later Ordovician and Silurian time. South of the Ettrick Valley Fault (thought to represent a fundamental plane of décollement), the Silurian rocks show intense multiphase folding (though little cleavage) associated with strike-slip faulting.



Hutton's unconformity, Siccar Point, near Berwick on Tweed, England. The section shows near-vertical Silurian rocks overlain with gross unconformity by almost horizontal Old Red Sandstone strata; it is the locality at which James Hutton first appreciated the significance of unconformities. (Photo courtesy National Museum of Wales)

Lake District - Isle of Man

The north of England is apparently floored by 'Pentevrian-Cadomian-type' deep basement, below which the Moho, at about 30 km, is particularly shallow. The exposed succession starts with about 4 km of late Cambrian-early Ordovician turbidites, the Manx and Skiddaw Slates. Recent work has shown that vulcanicity (previously thought to have been confined essentially to Llandeilo time) occurred throughout the Ordovician. Submarine, tholeiitic lavas were extruded at first, followed by an accumulation of thick calc-alkali subaerial piles, weakly deformed and partially eroded by Ashgill time. Thin transgressive carbonate and clastic sequences of late Ordovician age were followed by several kilometres of Silurian turbidites.

The major deformation took place abruptly near the end of Silurian time, when polyphase folding and associated cleavage occurred within an arcuate slate belt convex to the NW. Granite plutons, emplaced at about this time, coalesced with subvolcanic intrusions of Ordovician age to form the granitic foundation of the Lake District. The density contrast between these intrusions and their country rocks has controlled in large part the subsequent tectonic and sedimentary history of the whole region.

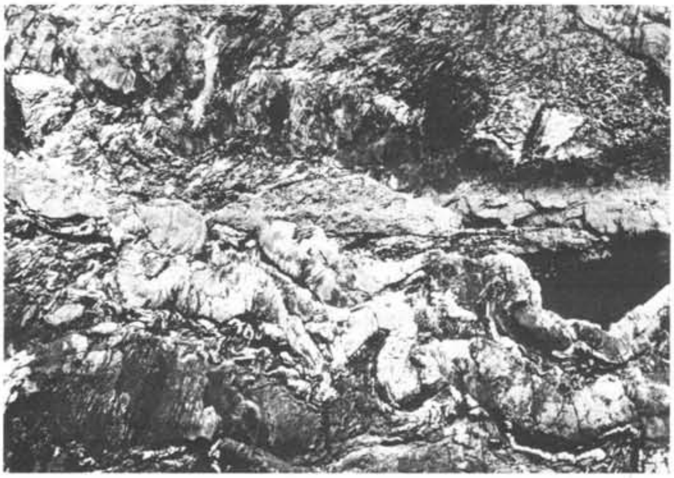
Irish Sea Horst

Pre-Caledonian metasediments and basement gneisses of the Mona Complex are thought to have formed a positive region trending SW through Anglesey in early Palaeozoic time. The principal evidence for this - absence of Cambrian rocks in Anglesey in contrast to their thick development on the mainland and the north-westerly Arenig overstep of Cambrian and earlier formations - has now been weakened. A major part of the Mona 'Bedded Series' (including the Gwna olistostromes) is now known to be of Cambrian age (Muir et al., 1979), and structural re-evaluations show that much of the multiphase deformation and metamorphism previously assigned to the Cadomian is Caledonian (Barber and Max, 1979).

Welsh Basin

Long regarded as a classical geosyncline, this area is still seen to comprise an ensialic basin filled by a thick sequence of dominantly shallow marine clastic and volcanic rocks of latest Precambrian (Arvonian) to Silurian age. Although strain studies have indicated that the sequence is thinner in certain areas than previously supposed, it is probably in excess of 10 km where bolstered by volcanic piles. The volcanics are dominated by acid, often ignimbritic volcanoclastics, and range in age from latest Precambrian (Arfon) through Arenig-Llanvirn (Cader Idris) to Caradoc (Snowdon). The volcanic outbursts were preceded by crustal updoming, followed by erosional overstep and accumulation of a thick Silurian flysch, later converted into a slate belt.

The tectonic pattern is more complex than that of the Lake District, and the strain diminishes markedly toward the SE margin where, in the Welsh Borders, there is a sedimentary transition upward into continental Devonian. As in the Lake District, the main deformation appears to have taken place close to the end of the Silurian or in the early Devonian. Recent suggestions (Davies and Cave, 1976) that the cleavage is an early diagenetic feature associated with primary dewatering of sediments have not met with acceptance. In contrast with the Lake District and Southern Uplands, no

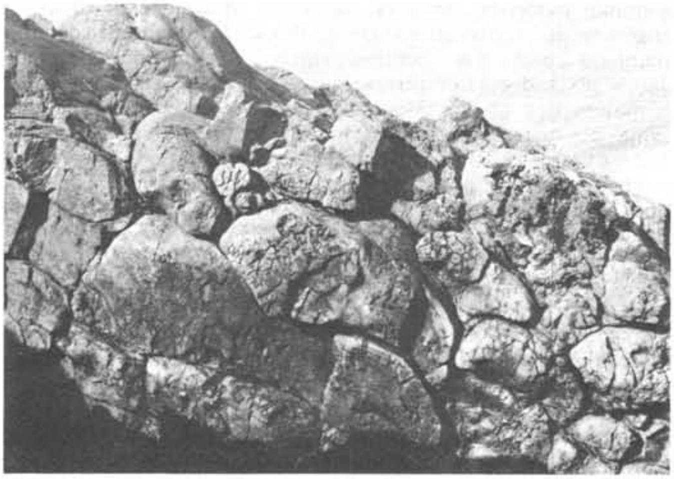


Cliff section SW of Rhoscolyn, Anglesey, North Wales, showing folded metamorphozed turbidites of the South Stack Formation, part of the Monian Supergroup. The latter was deposited in late Precambrian times, and may represent an early Caledonian geosynclinal basin fill. (Photo courtesy National Museum of Wales)

major Caledonian granites are found in this region at the present level of exposure, although subvolcanic and hypabyssal intrusions are widespread.

Midland Craton

The Welsh Basin is flanked to the SE by an apparently isolated cratonic area which is characterized by thin, 'shelf' sequences of weakly deformed Lower Palaeozoic strata. The accessible sub-Cambrian rocks comprise altered gneiss remnants, probably of late Proterozoic age, and a varied cover sequence dominated by coarse clastics and acid volcanics, considerably deformed and faulted with minimal metamorphism in latest Precambrian time.



Pillow lavas of the Fishguard Volcanic Group, South Wales, U.K. - products of an episode of igneous activity during early Ordovician times. Average diameter of the long axis of pillow is about 75cm. (Photo courtesy National Museum of Wales)

Plate Tectonic Interpretation

It is widely accepted that a plate tectonic hypothesis which involves the creation and destruction of a major ocean (Iapetus) provides the only adequate uniformitarian interpretation of the Caledonide orogen. Evidence for the existence of Iapetus is provided by the provinciality of Cambrian and early Ordovician shelly faunas. Few surviving fragments of oceanic lithosphere have been identified with certainty, and the palaeomagnetic data from the opposing plates are insufficiently precise to define the width of the ancient ocean.

The strongly contrasting physical nature and age of stabilization of the deep basement to the north and south of the Southern Uplands, places the boundary between the Laurentian and Afro-Asian plates somewhere in that region. The tectonic style and aeromagnetic 'grain' change abruptly at the Solway Line (Fig.2), and this is now regarded as the most likely site of the Iapetus suture (Phillips et al., 1976). The climactic tectonism that affected the non-metamorphic Caledonides at the close of the Silurian can only be seen as a massive conversion of kinetic energy into work: collision-type orogeny.

Beyond these basic points, the details are far from clear. In particular, the geometry and timing of subduction are matters of continuing speculation because the evidence is generally scant and/or ambiguous. The multitude of hypotheses put forward over the last decade cannot be reviewed here, but some consensus views are emerging.

It is widely agreed that

- northerly subduction occurred in Ordovician time along a line close to the Southern Uplands Fault;
- the imbricate structure of the central Southern Uplands results from the accretion of a flysch wedge onto the northern continental margin;
- the Ballantrae complex represents oceanic lithosphere obducted northwards; and that
- southerly subduction took place in the Ordovician beneath the Lake District.

An earlier phase of northward subduction has been invoked to account for the Grampian Orogeny in the metamorphic Caledonides, and southward subduction at the Solway Line to explain the distribution of vulcanicity, not only in the Lake District, but in Wales. Both are acceptable working hypotheses. The recently proposed ideas that the end of subduction is marked by the cessation of vulcanicity is less acceptable: it implies that no significant subduction occurred in the Silurian. The corollary - that the cessation of vulcanicity indicates the moment of collision - is refuted by evidence from the Lake District where vulcanicity terminated in the Ashgill, to be followed by a period of quiescence in the early Silurian. Even wilder speculations - for example, the proposed 960-km wrench displacement on the Solway Line (Phillips et al., 1976) - have no foundation. Nonetheless, collision, in the general case, is likely to have been diachronous and oblique, and to have generated non-coaxial strains and wrench displacements.

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Non-Metamorphic Lower Palaeozoic Rocks of Ireland

by

P.M. Bruck

The Lower Palaeozoic sequence on the northwestern side of the Solway Line (Iapetus Suture) in Ireland (Phillips et al., 1976) is essentially an extension of the Scottish Southern Uplands. Its main developments are in Longford-Down, Tyrone, Mayo, Galway and the northern central inliers.

The oldest rocks occur in the north and comprise, at the base, a thick succession of lower and middle Ordovician volcanics. These are overlain by upper Ordovician turbidites with cherts, slates and volcanics exposed chiefly in the region of Longford-Down. In Mayo and Galway, Silurian shelf rocks and turbidites rest unconformably on older strata. In Longford-Down, however, the Silurian is thick, conformable, and turbiditic; the structure is complex and similar to that of the Scottish Southern Uplands.

The succession SE of the Iapetus Suture is comparable with that in the Lake District. At Leinster, the rocks range upwards in thick, continuous and discontinuous sequences, from Lower Cambrian to Llandovery, and in Slievenamon from Upper Cambrian to Wenlock. In the eastern inliers, both Ordovician and Silurian sequences occur, while the western Lower Palaeozoics are entirely Silurian. Sandstone and siltstone turbidites dominate all the successions.

There are also important volcanics, particularly of upper Ordovician age in Leinster, lower-upper Ordovician age in the eastern inliers, and Wenlock in Dingle in the southwest. The structure is defined by major and minor upward facing folds with a variably developed cleavage, generally dipping steeply to the southeast.

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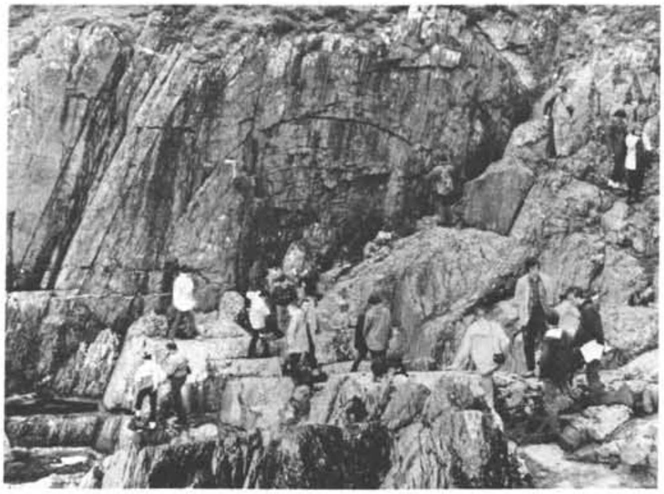

Late Lower Silurian (Upper Llandovery) red siltstone, slate, graywacke in an anticline of Caledonian age, Clogher Head, Leinster zone, Co. Louth, Ireland. (Photo courtesy W.H. Poole)

Caledonides of East and North Greenland and Svalbard

by

N.J. Soper

East Greenland

The East Greenland Caledonian orogen underlies a 50-200 km-wide tract between the coast and inland ice from 70°N to 82°N. The tectonic trend is roughly N-S and the western margin is overthrust. Much of the belt is composed of gneiss complexes. In the south, the Flyverfjord infracrustal complex has yielded Archaean isotopic ages (ca 3000-2300 Ma) and is overlain by a cover sequence (the Krummedal supracrustals) which underwent orogenic deformation in mid-Proterozoic time (ca 1245-1000 Ma).

Between 72°N and 74°N, gneisses form involuted domes and mushroom shapes mantled by metasediments which, in the classic interpretations of Backlund, Wegmann and Haller, were regarded as Caledonian migmatite fronts. Recent research (Higgins, 1976) favours an origin in the multiphase interfolding of basement gneiss and later cover, and this is supported by the early Proterozoic (ca 2000-1700 Ma) isotopic ages on the gneisses. The region was evidently the site of an extensive early Proterozoic mobile belt. An obvious comparison can be drawn between the three pre-Caledonian orogenic cycles of East Greenland and the Scourian, Laxfordian and Grenville-Morarian of northwestern Scotland.

Between 76°N and 81°N, a thick sedimentary sequence previously referred to as the Thule Group (from an assumed correlation with the Thule Group sensu stricto of NW Greenland - now not accepted) is affected by Proterozoic open folding assigned to the Carolinide orogeny. Gneisses between 76°N and 78°N were thought to result from a Carolinidian phase of crustal reworking, although a sample from these gneisses, yielding an Archaean age, has thrown doubt on the orogenic status of the Carolinides.

Late Proterozoic sedimentation was widespread. In the north, the Hagen Fjord Group attains 5 km in thickness. South of the fold belt, the Eleonore Bay Group comprises a lower 8 km sequence of deltaic and fluvial quartzites and shales (reminiscent of the Grampian Group of the Scottish Dalradian), and an upper 4 km containing stromatolitic carbonates; the latter extends into the late Riphean and has similarities with the Appin Group of Scotland. The whole sequence is non-flyschoid; previous reports of an ophiolite complex near the base are erroneous.

The Eleonore Bay Group is overlain unconformably by the Tillite Group (< 1 km) of Vendian age, which can reasonably be associated with other late Proterozoic tillite sequences in the North Atlantic region. About 3 km of Lower Cambrian to Middle Ordovician platform carbonates with a Pacific fauna follow; Skolithos quartzite is known from erratics. These Palaeozoic sediments bear a close similarity to shelf successions of Durness, Scotland and Western Newfoundland. Flyschoid basinal sequences of this age are unknown in East Greenland.

Caledonian deformation is less intense than previously supposed and generally takes the form of open N-S folds in the cover, with large scale westerly-directed thrusts in the basement gneisses and along the western margin. Metamorphism of the cover is only significant in the lower part of the Eleonore Bay Group, but reaches amphibolite-facies in the pre-Caledonian basement gneisses where it is often sufficiently intense to reset Rb-Sr mineral, but not whole rock, systems. Mineral ages suggest stabilization in the interval from late Ordovician to early Devonian in different areas. Granitic intrusives, mainly confined to the southern half of the fold belt have, in the few examples dated, given Ordovician ages. There are very thick late orogenic intermontane molasse deposits of Middle and Upper Devonian age.

North Greenland

An E-W trending Caledonian fold belt occupies northernmost Greenland (N of 83°N) and continues into the Canadian Arctic Archipelago as the Franklinian mobile belt. South of the fold belt in Greenland, an undeformed platform sequence consists essentially of late Proterozoic-'Eocambrian' siliciclastic sediments, Lower Cambrian-Silurian shelf carbonates and late Silurian flysch. The platform carbonates pass rapidly northward into basinal arkosic and calcareous turbidites. The shelf edge was defined by E-W syn-sedimentary faults which migrated progressively southward through early Palaeozoic time.

The fold belt coincides approximately with the flysch basin, and its southern margin is quite abrupt but unthrust. Multiphase folds verge northward and intensify in that direction, accompanied by an increase in metamorphic grade to amphibolite-facies on the north coast. The fold belt is terminated in the north by a Tertiary thrust zone with greenschist mylonization which transported the metamorphics over late Palaeozoic sediments and late Mesozoic volcanics (Kap Washington Group).

The major tectonic evolution of the fold belt is believed to be Caledonian. The oldest cover rocks recorded are Upper Carboniferous or Permian; no Devonian cover has been identified in the region. Basement gneiss is not involved in the fold belt at the level exposed, but amphibolite-facies gneiss xenoliths are recorded from volcanic necks. There are no Caledonian plutonic rocks.

Svalbard

Although pre-Atlantic reconstructions place Svalbard (Spitsbergen) in juxtaposition with the Wandel Sea shelf, where the projected trends of the East and North Greenland fold belts meet, the geology of Svalbard throws little light on the inter-relationship of these belts. Perhaps, if Harland's (1978) hypothesis is accepted, this is because Svalbard would appear to comprise three distinctive Caledonian provinces, originally widely separated and brought into juxtaposition by major, late Devonian wrench displacements.

The eastern province includes the Ny Friesland peninsula, type locality of the well-known Hecla Hoek succession, which has Cambro-Ordovician carbonates with Pacific faunas at the top, and ranges down through tillites and carbonates into an enormously thick, largely volcanogenic clastic sequence whose metamorphic grade increases with depth. The upper part has similarities with upper Eleonore Bay and later sediments of East Greenland; in both the eastern and central provinces, the main tectogenesis (the Ny Friesland Orogeny) took place in mid-Silurian time.

The successions in the western province are characterized, at least in the upper parts, by turbidites of the Holtedahl Geosyncline, subjected to easterly directed thrusting and folding in late Silurian or Devonian time. Affinity with the North Greenland-Franklinian mobile belt is evident.

According to Harland's hypothesis, in early Palaeozoic time the western province was much closer to North Greenland while the eastern province was closer to East Greenland. This idea awaits a definitive test, which could perhaps be provided by palaeomagnetic studies.

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Caledonian Fold Zones Peripheral to the North Atlantic Caledonides

by

F.W. Dunning

The extent and degree of Caledonian folding on the continent of Europe SE of the North Atlantic Caledonides and SW of the East European platform are not easily determined, mainly because early Palaeozoic strata are not commonly exposed or are difficult to recognize within areas of Hercynian and/or Alpine folding.

There are some unequivocal Caledonian fold-zones such as the Brabant massif, the Ardennes massifs, and the Rügen-Pomeranian belt under the North German-Polish plain. There are regions such as the Sudeten in which the existence of Caledonian orogenesis has been vigorously disputed and even discounted. There are also those parts of the Bohemian massif, the Alpine massifs and crystalline nappes, the Schwarzwald, Vosges and Massif Central which have given abundant Rb-Sr isochron ages in the Caledonian range 350-500 Ma, reputedly dating high-grade metamorphic and magmatic events (Jager, 1977).

Autran and Guillot (1977, Fig. 4) have devised a pre-Atlantic reconstruction showing a Caledonian (essentially Acadian) metamorphic belt extending from the Massif Central through Newfoundland into the Appalachians. The same belt presumably spreads out eastward to the Bohemian massif and the Alpine zone, as shown in Figure 1. If this is a real Caledonian orogenic belt - and good stratigraphical evidence for this seems to exist only in the northwestern Massif Central, at Limousin - it must constitute some sort of 'Pan African'-type internides to all the external Caledonian fold-zones to the north, that is, Brabant, Ardennes and Rügen-Pomerania.

On evidence available at present, it is not possible to connect the Brabant-Ardennes fold-zone across north Germany to the Rügen-Pomeranian Caledonides. In fact, the clear discordance between the strongly folded Lower Palaeozoic and the Devonian (Gedinnian) in the Ardennes massifs cannot be traced eastward into the Rheinische Schiefergebirge; neither can the discordance between folded Silurian and Givetian in the Brabant massif be traced westward beyond the Région du Nord in NE France.

The Brabant massif apparently extends under the Mesozoic cover into SW England in the region north and south of the Thames Estuary. But it is difficult to establish a connection with the NW British Caledonides on land, via the East Midlands Caledonian aulacogen of Evans (1979), or off the coast of East Anglia via the Mid-North Sea geosyncline of Wills (1978) on the scant borehole evidence.

The Rügen-Pomeranian Caledonides situated on the SW boundary of the East European platform (as proposed by Tornquist) comprise an 8-10 km-thick Ordovician-Silurian miogeosynclinal sequence (Dadlez, 1974) strongly overfolded toward the platform. Under the name of "Danisch-Polnische Tafelrandsenke" (Franke, 1977), it may underlie northern Denmark. The big question then, is whether or not it crosses the North Sea to connect with the non-metamorphic Caledonides in Britain. This latter geotectonic unit, comprising thick volcanic and flyschoidal formations characterized by mediotype folding, is unrepresented in Scandinavia.

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HERCYNIAN EUROPE

by

F. Ellenberger and A.L.G. Tamain

In Upper Palaeozoic times, nearly the whole of southern Europe was affected by Hercynian movements which led to the formation of the Variscan folded chains (Variscides). This article describes three major regions of the Variscides: the northern zones, extending from the Variscan front to the Ligerian line, including the axial part; the southern zones - from the Ligerian line to the Alpine foredeep, and the Iberian Meseta of Spain and Portugal.

The northern limit of the Variscides - the "Variscan front" - can be traced from southwestern Ireland, through southern England, the Boulonnais and the Ruhr, as far as Silesia, where it disappears beneath the Carpathians (Fig. 1). A large part of this area was later affected by the Alpine orogeny. The part that remained outside of the future Alpine mobile zone is what H. Stille called "Meso-Europe".

This quasi-platform, established in late Palaeozoic times, was warped into a pattern of basins and swells from Triassic time onwards. The study and reconstruction of the Variscan orogen is complicated by its consequent fragmentation into isolated "Hercynian massifs" which are anything but homogeneous: they include elements of much earlier deformations (Caledonian, Cadomian, and even older), as well as strictly Hercynian components.

Northern foreland

North of the Variscan front, the northern (Epicaledonian) foreland is best exposed in Brabant. It has been encountered at depth from boreholes in Holland, Westphalia and the neighbouring regions. This margin of the North European platform is covered by Devonian continental deposits in discontinuous (Old Red Sandstone) basins, or by a thin post-Eifelian (early Middle Devonian) cover overlain by neritic carbonate sediments in the Lower Carboniferous (Dinantian), and by paralic molassic deposits in the Namurian and Westphalian (productive Coal Measures).

The whole of the Epicaledonian foreland suffered the after effects of Variscan folding, which took the form of swelling and tilting movements (of variable intensity), and of block faulting.

Subvariscan zone and Variscan front

The Subvariscan zone (Subvariscan foredeep or Westphalian zone), the most external unit of the Variscan, appeared in the Upper Carboniferous at the southern margin of the Epicaledonian foreland as the latter subsided. Together with the Rheno-Hercynian zone, it constitutes the externides of the Meso-European Variscides, though it is distinguished from this zone by its paralic molassic sedimentation and its

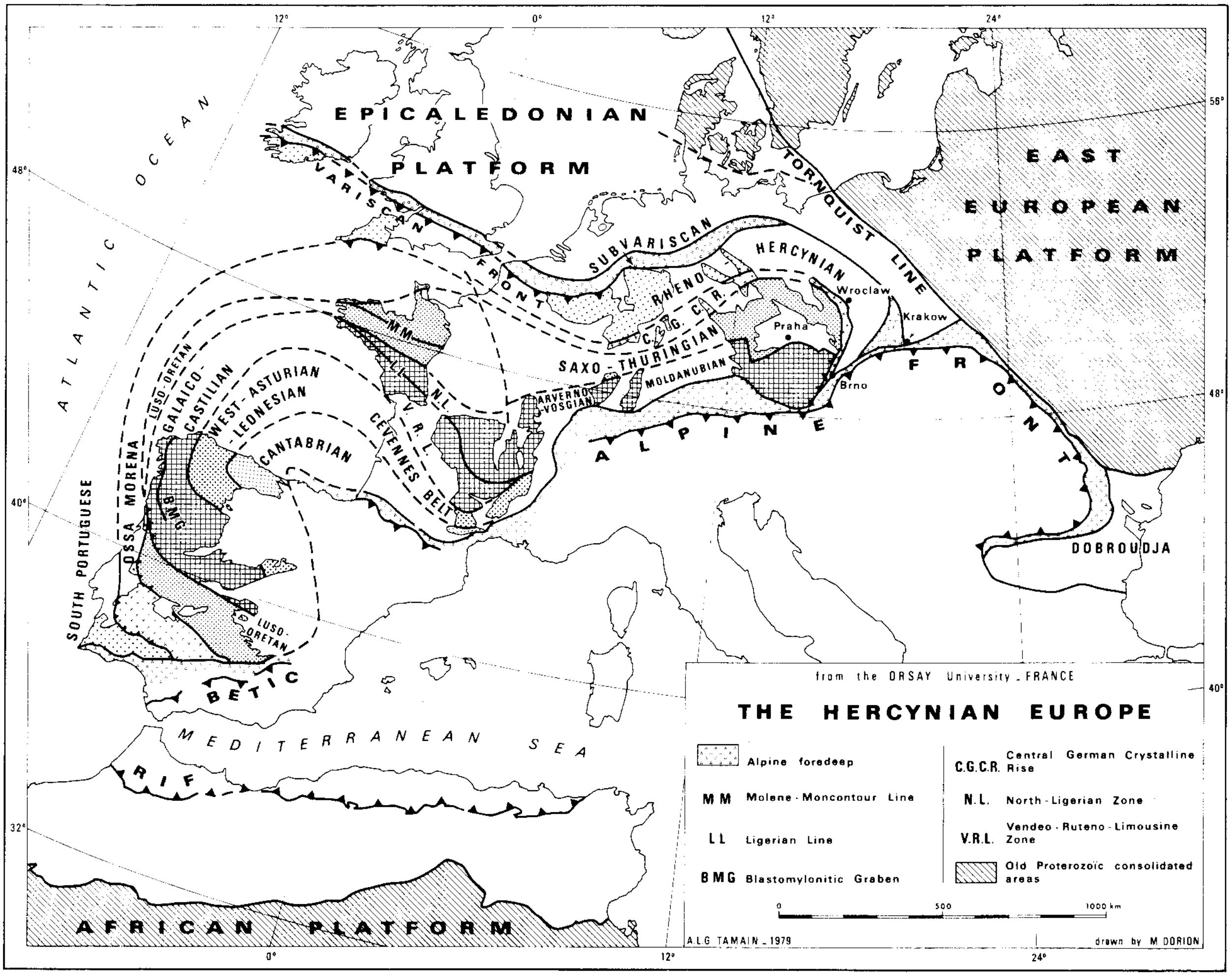


Figure 1. *Map showing major zones of the Hercynian in Europe.*

productive Coal Measures, folded during Asturian tectonism.

A belt of major late-phase tangential fractures, cutting folds already formed, emphasizes the Variscan front from Wales to the Rhine. For example, the Ardennes have overthrust the Franco-Belgian coal basin along the "Faille du Midi" (Condroz thrust or Eifel fault). Similarly, in southernmost Wales and the Mendip Hills, Devonian and Dinantian deposits have overthrust the Coal Measures. The amplitude of the total tangential compression is variable, the cumulative shearing movement of the thrusts exceeding 40 km in the Namur syncline, and 15-25 km near Bristol.

The "Green Bridge of Wales" - a natural arch eroded in Lower Carboniferous limestones, Castlemartin, Pembrokeshire, Wales. (Photo courtesy National Museum of Wales)

SYSTEM	SERIES		STAGE		LOCAL FACIES	OROGENIC EVENT
PERMIAN	Upper					SAALIAN
	Lower					
CARBON-IFEROUS	Upper	SILESIAN	Stephanian	C		
				B		ASTURIAN
				A		
	Middle		Westphalian	D	Coal Measures	
				C		
				B		
				A		
			Namurian	C		ERZGEBIRGIAN
				B		
				A		
	Lower	DINANTIAN	Visean		Culm	SUDETIAN
			Tournaisian			
DEVONIAN	Upper		Fammenian			BRETONIAN
			Frasnian			
	Middle					

Table showing stage names, facies and orogenic events commonly referred to in the Hercynian of Europe.

Carboniferous (Tournaisian) Culm comprising black shale, oil shale, and black quartzite, Maine, France. (Photo courtesy W.H. Poole)

Northern Zones

Rheno-Hercynian zone

The Rheno-Hercynian zone comprises Cornwall and Devon, the Ardennes (with the Dinant and Namur basins), the Rhine schistose massif, the Harz and the Flechtingen-Rosslau massif. Its continuation is in the Nisky Jesenik mountains of Sudetenland. According to Aubouin (1965), the following may be distinguished in it: an external miogeosynclinal trough (Brocken, Sauerland, Stavelot, Eifel, Dinant, Rocroi); a central miogeanticlinal ridge (Siegerland); and an internal eugeosynclinal trough (Taunus, Hunsrück).

Stratigraphy

Devonian sediments generally lie discordantly on the Cambro-Silurian substratum. They are mainly shaly or sandy and may be very thick. In Upper Devonian, Hercynian mobilization was marked by the formation of carbonate swells and troughs with argillo-siliceous sedimentation. During Famennian time, in the southern Rhine schistose massif and the Harz, fine clastic sedimentation predominated, but the presence of conglomerates and flyschoid deposits of material derived from the Central German Crystalline Ridge further to the south indicates precocious movements. At the close of the Devonian, slight uplift and regression affected the margins of the Rheno-Hercynian zone and its component units (see Table for European stage names).

On the eastern edge of the Rhine schistose massif and the Harz, flysch sedimentation which began at the end of the Devonian with deposition of the first greywackes, culminated in the formation of the Viséan "Culm-Greywacke"; the latter included terrigenous deposits from the Central German Crystalline Ridge which accumulated in a "Culm trench" that gradually migrated NNW.

Sedimentation in the zone during the Dinantian was very thick, characterized by sequential displacement, with time, of the basins and then of the folding toward the northern foreland. Thus, Tournaisian sedimentation transgressed northward in the external zone, was affected by slight tectonic instability in the Viséan, and, in Namurian times, was again invaded by a northwestward transgression.

In SW England, mid-Devonian to Dinantian sedimentation also reveals a certain degree of tectonic instability. Flysch in southern Cornwall grade into reef limestones and spilites in south Devon, to marine shales further north, and finally to deltaic and littoral deposits in South Wales. Sites of deposition are small basins or trenches.

In Devonshire, the onset of orogenic activity in the Namurian was heralded by deltaic and thick distal turbidite deposits. Folding began at depth shortly before Namurian time, directly above the Cornish batholith as it started to ascend. In Westphalian time, the turbidite basin was filling up, sedimentation became coarser and coarser, tectonic deformation intensified, and the ascent of the Cornish batholith resulted in a geanticlinal uplift with paralic sedimentation in north Devon.

Late Devonian and Dinantian vulcanism, similar to present-day continental basalts, had a distinct bimodal (basic and acid) chemistry. Alkaline, rich in Ti, it is represented by a characteristic spilite-keratophyre association in the Harz, SW England, and the Rhine schistose massif (which also includes spilitic diabases, picrites and rare ultrabasic cumulates with olivine).

Tectonism

Variscan folding migrated from basins already filled to those which were in the course of being filled. This progression began in the Viséan in the southern part of the zone, affecting the rest of the area during the major deformation (Asturian phase) which took place between the Westphalian C and the end of Stephanian.

Tectonics are simple in outline but complex in detail. For example, numerous isoclinal folds overturned to the NNW, accompanied by a generalized slaty cleavage, were cut by minor late-phase thrusts. Regional metamorphism is either lacking or weak (Ardennes, eastern Harz, Hunsrück). The only known granites are post-tectonic, late Carboniferous, and intrude the country rock, as in the Harz (Brocken) and Cornwall (where they are tin-bearing).

From a geophysical point of view, the Rheno-Hercynian zone appears as a trench filled with up to 10 000 m of Palaeozoic sediments (in the Dinant basin), apparently situated above an area of crustal thinning.

Central German Crystalline Rise

The Central German Crystalline Rise (or Ridge) includes highly metamorphosed Precambrian and pre-Hercynian formations caught up in the Hercynian deformation. Outcrops are restricted to the small Ruhla-Brotterode (NW Thuringia), Spessart and Odenwald massifs. Everywhere else it is buried either beneath the molasse of the mid-Carboniferous internal trough that forms the Saar coal basin, or beneath younger, Mesozoic cover. On the south it is bordered by the narrow Schladerbach-Doberlug synclinorium.

Uplift started in the Upper Devonian, reaching its peak during the Viséan. Deformation led to overturning; in the Upper Viséan, the region became a synclinorium in which discordant "post-tectonic" molasses were then deposited, accompanied by andesitic extrusions.

Authors generally interpolate the ridge westwards, beneath the Paris Basin, reappearing in the western Channel as the gneissic basement of the Pays de Bray and the coast of Cornwall (Start Point, the Dodman, the Lizard), where it is bounded to the north by a great overthrusting suture. Its southern limit cuts the corner of the Cotentin peninsula (with the 2500 Ma old granitic gneisses of the Nez-de-Jobourg, Omonville and the Trégorrois).

The ridge appears to extend eastward from Berlin, describing an arc (convex to the north) which disappears near Wroclaw.

Saxo-Thuringian zone

In Central Europe, the Saxo-Thuringian zone is made up of the following units (from NW to SE): an external region comprising the Schwarzburg-Leipzig-Lausitz anticlinorium; the central Saxon synclinorium, including the two brachy-anticlinorial structures of the Berga and the Granulitgebirge, the Münchberg gneissic massif, and the two intermediate Saxon Wildenfels and Frankenberg massifs; and an internal region which includes the Fichtelgebirge and the Erzgebirge anticlinorium.

Stratigraphy

The zone experienced a long sedimentary and magmatic history in the Proterozoic and Lower Palaeozoic. Hercynian mobilization began in the Upper Devonian with greywacke sedimentation in the northern part and thin neritic sedimentation in the south. The earliest neritic deposits are covered by unconformable transgressive neritic limestones of Dinantian age (in the Erzgebirge). An extensive late Devonian magmatic event occurred in certain tectonically unstable sectors of the external region (such as a few of the basic and ultrabasic intrusions around the Erzgebirge), and was accompanied by Lahn-Dill-type mineralization. This was followed by flysch deposition (greywacke, conglomerate and limestone). Palaeogeographic units retained their positions throughout the zone and did not migrate as in the Rheno-Hercynian zone.

Tectonism

The main phase of folding was early Sudetic (early to middle Viséan) to Erzgebirgian. It was accompanied by a general metamorphism, weak or absent in the north, but more intense in the south (Erzgebirge, Fichtelgebirge), and by well marked synmetamorphic deformation, including thrusts. In the central Saxon synclinorium, the mesozonal crystalline basement is thrust over Palaeozoic (including Dinantian) formations.

There is, however, no definite evidence for or against the suggestion that the Münchberg massif is a fragment of a vast crystalline nappe overthrust to the north.

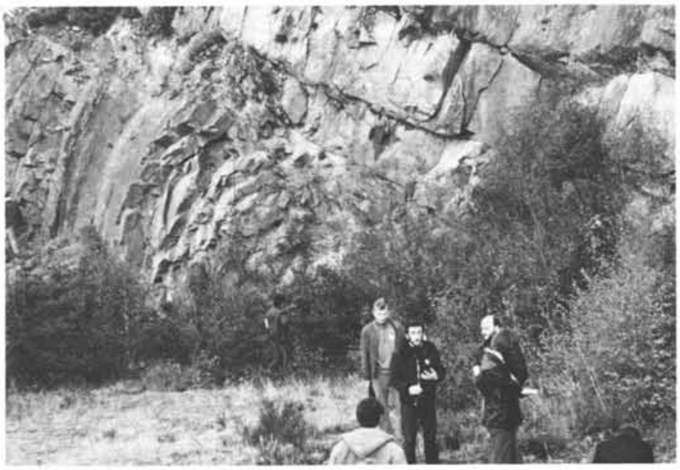
In the southern part of the central Saxon synclinorium, Upper Viséan molasses were folded by Erzgebirgian movements, covered unconformably by molassic Westphalian B-C deposits, eroded, and, following Saalian movements, sealed by unconformable, transgressive Permian deposits.

Further south, the onion-scale gneissic cupolas of the Erzgebirge display folds of the Variscan infrastructure, which possibly resulted from the reworking of Cadomian granitic intrusions. The main phase of folding was followed by acid plutonism (with high original metal content), which reached its peak in the Upper Carboniferous. This region experienced a "subsequent" vulcanism during a period of over 60 million years, extending from the main (Asturian) phase to the mid-Permian (Saalian). This intermediate-to-acid vulcanism was located at the junctions of major fractures descending into the upper mantle.

Extension of zone

Eastward (beyond the "Elbe lineation"), the Saxo-Thuringian zone continues in the western branch of the Sudeten mountains, where it differs little from the type region in Saxony and Thuringia. Westward, the zone continues into the northern fringe of the Black Forest and the northern Vosges (north of a line from Saint-Dié to Sélestat).

It is common to continue this zone westward beyond the Vosges, beneath the southern half of the Paris Basin, as far as the Armorican massif. Although there are no outcrops for 500 km, this interpolation is supported by numerous lithofacial and biostratigraphic correlations, not only of Hercynian but also of Caledonian age. For example, a so-called external limestone belt (of Lower Cambrian and early Middle Cambrian age) with stromatolites, Archaeocyathan colonies and associated acid vulcanism (Doré et al., 1977), stretched from Breslau through Lusatia and the Fichtelgebirge as far as the Cotentin, and from there to the Ossa Morena (Cordoba) in the southern Iberian Meseta.



Well bedded late Cambrian to Tremadocian conglomerate and red shale lying with angular unconformity on nearly vertical Brioverian siltstone and grit of Hadrynian age in the Armorican massif, 30 km west of Rennes, France. (Photo courtesy W.H. Poole)

In Normandy and north Britanny, the zone is characterized particularly by the late Cadomian acid rhomboidal plutonic block of the Mancellia. It extends also into central Armorica, where it is cut by the major E-W "Molène-Moncontour lineation" which can be traced for over 350 km (Fig. 1). It is a major crush zone, with elements of basement, packages of basic and ultrabasic rocks of oceanic affinities (Belle-Isle-en-Terre), Hercynian tectonic slices, and Variscan leucogranites (Cogné and Jest, 1977). The central Armorican province, limited to the south by a great linear fracture - the Ligerian line - is underlain by early Carboniferous sediments and volcanics.

In the Laval Basin, for example, a Tournaisian shaly and conglomeratic series includes acid subaerial volcanics with rhyolitic ignimbrites and keratophyres, succeeded in the Lower to Middle Viséan by outpourings of acid tuffs. Further west, in the Chateaulin basin, Tournaisian diabase of tholeiitic basalt composition was extruded, along with a spilite-keratophyre series which included lava flows, pyroclastics, and a siliceous Fe-Mn facies.

Moldanubian zone

This zone constitutes the axial portion of the central European Variscides. It corresponds not so much to an inert intramontane block ("Zwischengebirge") as to an eugeanticlinal zone whose deformation was accompanied by low-pressure/high-temperature metamorphism, and by the emplacement of granite magmas.

The zone was first defined in the central and southern Bohemian massif, where the Precambrian basement consists of an early (Moldanubian) cycle which ended at about 1000 Ma, and a later (Algonkian or Brioverian) cycle of the Cadomian orogeny with amphibolite-facies metamorphism. To the north, the highly fossiliferous and scarcely folded shales of the Palaeozoic, rest unconformably on the "Algonkian" substratum.

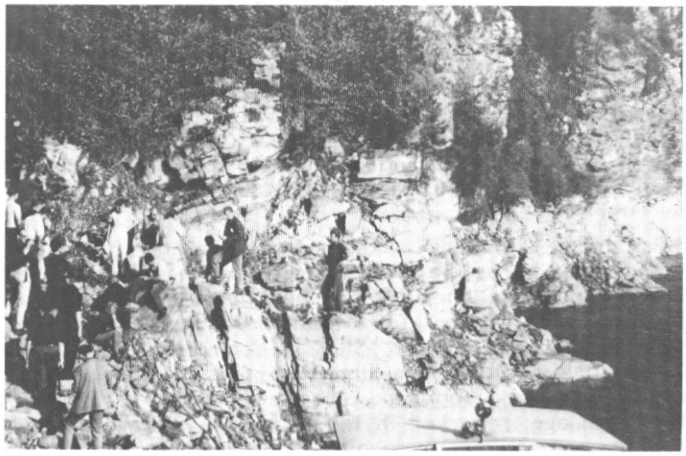
The Hercynian cover is thin, with neritic shelf deposits (locally as old as late Devonian), Breton emersion, unconformable Dinantian deposits of Culm facies, and very local but intense trachy-andesitic vulcanism and back-deep granodioritic instrusions. After a mid-Carboniferous interval, freshwater (lacustrine) deposits were laid down unconformably in Upper Carboniferous times in narrow, fault-bounded basins.

Variscan tectonism comprised Breton, Sudetic, Erzgebirgian and Saalian movements, which terminated at the end of the Permian with a crustal consolidation, forming a typical Epivariscan platform or shelf. Regional metamorphism reached only the greenschist facies.

To the southeast, the Moldanubian zone overrides the Moravian zone, the latter forming part of a larger ENE-WSW trending complex transverse to the main Variscan lines; it is thought (Andrusov, 1976) to be mainly Rheno-Hercynian. The Saxo-Thuringian zone is pinched in further to the northwest, where it disappears progressively beneath the Moravian thrust (Fig. 1).

The Moldanubian zone extends westward as the substratum of Bavaria, the Black Forest (of which it forms nearly the whole), the central and southern Vosges, and then as the north central region of the Massif Central (Arverno-Vosges massif). Its northern limit in France is traced by a band of leucogranites running from the Vosges to the Morvan, from where it joins the southern Armorican shear zone as far as the Pointe-du-Raz on the coast.

In the Massif Central, the zone includes Barrovian cordierite gneisses and anatexites (Rb/Sr ages of 670-650 Ma) with relict paragneisses of granulites, micaschists and gneisses. These are overlain unconformably by Upper Devonian sediments of Culm facies and albitite vulcanics. They in turn are covered by transgressive early Viséan neritic marine deposits and late Viséan ignimbritic volcanism (anthracite-bearing tuffs). Biotite granites were intruded from the Devonian to the Westphalian, while the biotite-cordierite granite at Guéret is considered to be a late palingenesis of the anatexites.



Highly granitized Precambrian (Gföhl) gneisses which were possibly affected by Hercynian movements in the Moldanubicum of the Bohemian massif, SW of Brno, Czechoslovakia. (Photo courtesy L.P. Tremblay)

The Moldanubian zone is thought to reappear in the Armorican massif in the North Ligerian zone (Fig. 1). It is bounded to the north by a lineation running from Pointe-du-Raz to Angers, and to the south by the great "Ligerian Lineation" (or the southern Armorican crush zone). This line is a major intracratonic suture, characterized by sheared strata of the Rutheno-Limousin zone through overthrusting by the Moldanubian both in pre-Westphalian and in post Stephanian times. In addition, it is the site for post Dinantian leucogranites generated by crustal anatexis.

In this region, the Cadomian basement is made up of Brioverian metasediments associated with basic and ultrabasic rocks: serpentinized dunites (with Cr-Pt), metagabbros (with ilmenite-magnetite + Ni), greenschists with pillow lavas, tuffs and siliceous schists. The formations are metamorphosed in the west but not in the east. The basement displays nappes and is granitized. Radiometrically determined ages of 550 Ma suggest a Lower Palaeozoic age for the main tectono-metamorphic development of parts of this basement. It is covered by discontinuous and incomplete Palaeozoic epicontinental deposits, including transgressive Middle Cambrian to early Ordovician deposits.

The region has remained above sea level practically since the Lower Devonian. Hercynian granitization played an important role, especially in exploiting lineations. A few small Stephanian coal basins also developed in the fault-bounded basins related to these fracture-lines.

The striking Hercynian fracture network is syn-kinematic at least in part (Tamain, 1975, and Rossi and Tamain, 1975), and certain lineations are metallogenetic "vectors" (for example, the Pointe-du-Raz to Angers for gold and lead, its southern Chalonnes satellite for lead). The same applies to certain granite-complex margins active at that time (such as Mortagen for uranium).

Southern Zones

The southern branch of the Variscides is best represented in southern France, though it is still little known. The following summary deals only with the parts that were not caught up in the Alpine orogeny.

Vendee-Rutheno-Limousin zone

In the Massif Central, this zone is characterized by a predominance of rhythmic sedimentation, abundance of basic volcanics, thick stratiform quartzo-feldspathic formations (which may represent the lowest part of the basement-cover) and, towards the top, by an epischistose series (with microfaunas of Ordovician, Silurian and early Devonian ages).

In Rouergue, the Barrovian metamorphism appears to be Caledonian or Reussian (430-360 Ma, Autran, 1978). This metamorphism is more or less obliterated by a second, Hercynian metamorphism, apparently that of the higher epischists and associated with either a Breton or Sudetic phase. In the Westphalian, the Limousin (already above sea level in the Dinantian), became the southwestern margin of the Arvernian nucleus.

This complex extends northwestward beneath the Poitou threshold as far as the south Ligerian province to form the Vendée-Limousin zone. The evolution of Vendée is not fundamentally different from that of the preceding region: schistose Ordovician and Silurian formations, a Lower Devonian hiatus, Givetian limestone reefs, another Upper Devonian hiatus, red sandstones and shales of possible Dinantian age, reworked in the Namurian. The Namurian deposits are not metamorphosed, but were deformed during an intra-Westphalian phase of folding.

This province, in the region of Saint-Nazaire, is characterized by a Cadomian magmatism and by a Siluro-Brioverian sedimentary complex (with basic and ultrabasic rocks of oceanic affinities). In addition, there are Cadomian orthogneisses, cut by acid plutonic rocks dated at 460 Ma. The province is also characterized by a complicated tectono-metamorphic development: on the one hand, there are migmatites and anatexic granites of 370 Ma; on the other, there are jadeite-lawsonite glaucophanites (symptomatic of a high-pressure/low temperature metamorphism) dated at 420-370 Ma.

Cevennes belt

The Precambrian history of the Cévennes belt in southern France (Fig. 1) is similar to that of the preceding zone. No Caledonian orogenic deformation can be detected in the northern Cévennes, aside from slight Middle Ordovician uplift in the Montagne Noire. In the southern region, early Carboniferous (Culm facies) deposits overlie Silurian and Devonian sediments.

The main phase of the Variscan orogeny is Asturian and is presumed to be early Stephanian. It is manifested in the north of the Montagne Noire and the Albigeois as recumbent folds with the development of an epizonal regional metamorphism. In the rest of the Montagne Noire and the Mouthoumet, it appears as a splendid development of nappes, in many cases overturned southward or southeastward (the vergence of folds and imbrication in the northern part is reversed).

Iberian Meseta

An extensive area of Variscides, the Iberian Meseta (or Hesperic massif/the Hersperides) of Portugal and Spain can be subdivided into six zones.

South Portuguese zone

The South Portuguese zone is characterized by:

- a late Devonian to Carboniferous sedimentation with vulcanism and associated sulphide mineralization, followed by accumulation of a very thick flysch series (Culm facies) in the late Viséan, which continued up to the Westphalian A in the southwest;
- migration of the Variscan palaeogeography and tectogenesis from SW to NE, followed by a major, post-Namurian (to post-Westphalian A?), pre-Westphalian D phase of folding, producing folds of SW to SSW vergence, along with shearing and thrusting to the SSW and, in places, weak metamorphism;
- Late Carboniferous (Coal Measures) deposition on the northwestern fringe;
- a late phase, post-tectonic plutonism with subvolcanic facies on the northeastern fringe, and very extensive metallogenesis, giving rise to the famous Huelva-Rio Tinto-Aljustrel pyrite belt.

This zone has been correlated with the Rheno-Hercynian zone, especially with the segment in SW Ireland.

Ossa Morena

The Precambrian of the Ossa Morena is characterized by a Cadomian substratum with large overthrusts. Early Palaeozoic carbonate deposition in the Cambrian became restricted to the south in the Ordovician, and was of variable thickness in the Silurian. It was overlain by Devonian epicontinental deposits, which were in turn followed by Dinantian and early Namurian flysch, restricted to trenches and paralic molasses with productive Coal Measures.

The zone was strongly deformed during post-early Namurian to pre-Westphalian D, producing folds with WNW-ESE axes and accompanied by a low to intermediate pressure metamorphism and a polyphase acid magmatism, with syntectonic, late-phase tectonic or post-tectonic phases.

The Ossa Morena is bounded to the north and northeast by the "Cordoba-Badajoz lineation" (which includes an alignment of basic and ultrabasic rocks of Tournaisian to early Viséan age); it is bordered on the north by a large polyphase calc-alkaline granite batholith. The zone has been correlated with the Central German Crystalline Rise.

Luso-Oretan zone

The Luso-Oretan (or Luso-Alcudian) zone is characterized by:

- a metasedimentary substratum of Cadomian age;
- deposition that was very thin and local in the Cambrian (Dore's internal carbonate belt), complete and thick in the Ordovician (with Taconic glaciation at the top), and epicontinental in the Silurian and Devonian;
- Sardian, Taconic and Reussian epeirogenic movements;
- continuous late Devonian and Dinantian (to early Namurian?) deposition with Culm facies in the Upper Viséan;
- deposition of Coal Measures with acid aerial vulcanism in the Stephanian and Autunian in the narrow Puertollano fault-bounded basin;
- a major post-Viséan to post-early Namurian phase of folding, producing WNW-ESE folds of SSW vergence, later sheared into numerous slices and accompanied in places by low-pressure metamorphism;
- a late-phase calc-alkaline granodioritic to granitic plutonism, well developed in Extremadura; and
- varied metallogenesis, pneumatolytic to hypothermal (with Sn and W) and vein-type mesothermal (with Cu, Pb, Pb-Ag).

This zone may be correlated with the Saxo-Thuringian as well as with the Norman-north Breton (in part) and mid-Breton provinces.

Galaico-Castilian zone

The Galaïco-Castilian zone provides the crystalline core of the Iberian structure. Cadomian basement, with its Braganza and Morais nappes, outcrops in a broad area and is covered unconformably by transgressive Ordovician followed by Silurian and early Devonian sediments. Coal Measures are confined to narrow internal basins.

Variscan tectonism is polyphase, its main phase not well dated (post-early Devonian and pre-Westphalian D, perhaps prior to 300 Ma). It produced recumbent folds of great amplitude, involving the Precambrian basement as well as narrow anticlines and synclines. It is accompanied by a metamorphism ranging from low pressure to Barrovian. Plutonism is of many facies and in phases that are synmetamorphic, syntectonic-to-late tectonic and late-to-post-tectonic.

The zone includes a broad suture, the "Blastomylonitic Graben" (Fig. 1), characterized by the presence of alkaline to hyper-alkaline acid plutons (which may originally have been ring structures, later metamorphosed).

West Asturian-Leonesian zone

This zone includes a partly metamorphic Precambrian basement (in the west) and is characterized by thick Cambrian, Ordovician and Silurian deposits, and thin early Devonian and pre-Stephanian Carboniferous deposits, with unconformable

Westphalian B-C Coal Measures.

Tectonism is polyphase. The major phase generated large recumbent folds verging toward the east and accompanied by low pressure metamorphism decreasing in grade eastward, apparently older than 310 Ma. The second phase sliced through the preceding structures and caused them to be overthrust eastward. The third phase, probably of mid-Westphalian age (pre-Stephanian B-C), refolded these last structures with reverse thrusting effects. There was also polyphase acid plutonism, decreasing in volume from west to east.

The zone has been correlated with the Cévennes belt.

Cantabric zone

The Cantabric zone is characterized by:

- unequally developed Cambrian, Ordovician and Silurian deposition, incomplete in many places and locally absent;
- thick Devonian deposition, with Asturia-Leon facies carbonates in the SW and Palencian pelagic facies in the SE;
- thick late Devonian to Carboniferous deposition, noteworthy for its calcareous Namurian flysch and its Westphalian paralic molasse (5000 m in the central coal basin); and
- continental Stephanian B-C deposits.

Tectonism is polyphase, the main "Palencian" deformation having produced overthrust sheets and imbricate structures. These were later refolded in an arcuate system of folds with vertical axial planes. A "Leonian" (intra-Westphalian D) phase produced a second system of radiating folds, with an Asturian compression phase and, finally, a late Saalian phase. Regional metamorphism is absent or weak. There is very minor late-phase to post-tectonic plutonism.

The zone has been correlated with the southern fringe of the Montagne Noire and the Mouthoumet.

Conclusion

For authors presenting ideas of the Variscan of Meso-Europe, a major turning point was marked by the preparation and publication in 1962 of the International Tectonic Map of Europe at 1:2 500 000: it provided both a synthesis of existing knowledge and an excellent working tool. It is to J. Aubouin, however, that one owes the first overall modern vision of the Variscides, for he was the first to take all the characteristics of their evolution into account.

The existence of a vast belt appearing between the ancient platforms of Africa and eastern Europe can now be established, and, within it, the general form of the great litho-structural zones and of the northern Variscan front, describing a vast double loop. There is a western, Ibero-Armorican loop, of northwestern convexity, with its axis formed by the Pyrenees, and an eastern, Moravo-Silesian loop, with northeastern convexity. This general zonation is more or less retained in the whole of Meso-Europe, in spite of reduction in width (extensive, in some places) of one or another internal zone.

Authors have often emphasized the bipolar symmetry of the Variscan belt, and the "centrifugal" propagation of the orogeny. We must point out, however, that in the Luso-Oretan zone (for example), assemblages of Erzgebirgian slices that had originally been thrust to the south and southwest were later moved to the north and northeast along the great mid-Westphalian thrusts. Thus, in speaking of orogenic polarity in such regions, it is important only to compare the vergence and/or displacement of units of the same age, or at least belonging to the same phase of deformation.

Certain characteristics are peculiar to the Variscan chain. These include: the very weak representation (by volume) of ophiolites; the appearance of a thermal crisis which, in the axial part of the chain, gives exceptionally high thermal gradients in the major phase, represented by low pressure metamorphism imprinted on an earlier Barrovian metamorphism; the control exerted throughout the early, main and late stages of tectonism by an impressive network of strike-slip faults on the geometry of the palaeogeographic units, tectonism, the emplacement of the magmas, and the localizing of the metalliferous mineralization.

Hercynian tectonism seems clearly to have been superimposed on a structural fabric, the framework of which had been formed by the end of the Cadomian. The Variscan belt is in an essentially ensialic framework where the continental crust is rarely older than 700-600 Ma.

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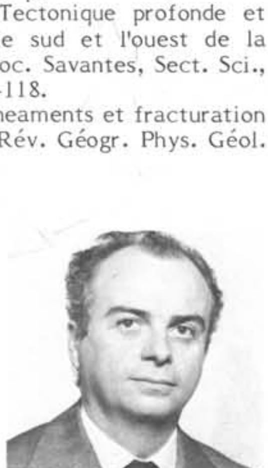

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ALPINE EUROPE

by

Jacques Debelmas

Formed from sediments accumulated in a branch of the Tethys between the Eurasian and African continents, the mountain chains of Alpine Europe may be divided into three major segments: the Pyrenees, which resemble an intracratonic chain but which originated in the transform zone on the northern edge of the Iberian craton; the "geosynclinal" chains - amongst the most sinuous and heterogeneous in the world; and the Aegean and Tyrrhenian arcs which exhibit a curious "Circum-Pacific" aspect lacking elsewhere in the Alps.

The Pyrenees

This chain originated in an early Cretaceous rift - the North Pyrenean zone - which was subsequently closed. It was subjected to thermal metamorphism in Cretaceous time, and later to high pressure metamorphism toward the end of the Cretaceous.

Those who accept the rift concept still disagree over the extent of the transform movement between the two margins of the rift. Some argue that there is little or no translation because palaeogeographic boundaries seem to extend without interruption on either side of the existing chain. Others feel that there was considerable displacement corresponding to the movement of the Iberian craton that followed the opening of the Bay of Biscay; hence, the North Pyrenean zone should be regarded as a true "transform zone". If one accepts the second hypothesis, it makes the Pyrenees a rather unique chain.

View of Cylindro (el Cilindro), Pyrenees, Spain. A northward closing syncline of Eocene carbonates overlies the obvious anticline of Paleocene strata. The summit of the mountain is formed by an allochthonous block of Maastrichtian (Upper Cretaceous). (Photo courtesy W.C. Morgan)

The Geosynclinal Axis

This Axis was formed as a result of the movement and eventual collision of two stable blocks - Europe and Africa. These movements were complicated by the existence of salients in the margins of each block: the Apulo-Adriatic promontory (Fig. 1) of the African craton (which played an important role in the genesis of the Alpine arc), and the Moesic promontory (Fig. 2) of the European craton (which influenced the formation of the Carpathian arc and the Balkan massif).

The Geosynclinal Axis itself is of opposing vergence with (i) an *Alpidic branch* on the edge of the European craton, overturned toward it, comprising the Betic chains, Corsica, the Alps, the Carpathians and the Balkan massif, and (ii) a *Dinaric branch* on the edge of the African craton, overturned toward it, comprising the North African chains (or Maghrebides), the Sicilian-Calabrian arc, the Appennines, the Dinarides and the Hellenides.

In each of these branches one can distinguish external zones (externides), a deformed part of the foreland affected only by late phases of folding (late Eocene to Neogene), and internal zones (or internides), separated from the externides by an important palaeogeographic and structural discontinuity, the appearance of which demonstrates the "Mesogean Jurassic stretching". Later, this discontinuity behaved as a zone of lateral movement or thrusting. On its internal side, in Jurassic time, there were intensely fractured areas which resulted from stretching under tension; the crust was thin and some strips of it were neo-oceanic.

This broad strain pattern was greatly reduced in some places from late Jurassic on, in others from about late Cretaceous on. The probable subduction of neo-oceanic crustal fragments led to the complex phenomena of overthrusting and high-pressure metamorphism.

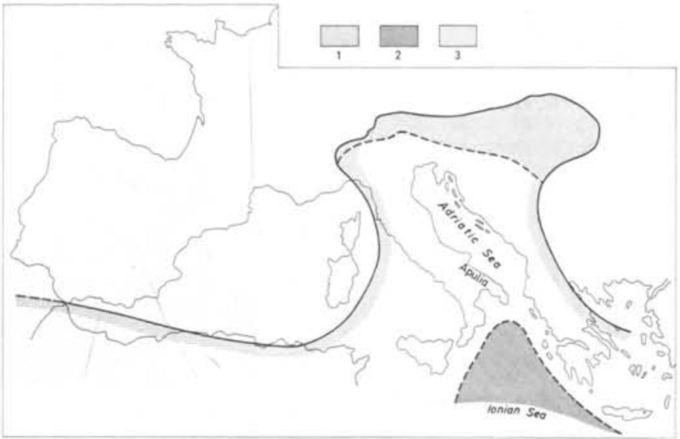


Figure 1. *The Apulo-Adriatic promontory of the African plate. 1: The overriding frontal portion (Austroalpine zone); 2: Zone of crustal thinning (Ionian sea); 3: Approximate limit of former African continent.*

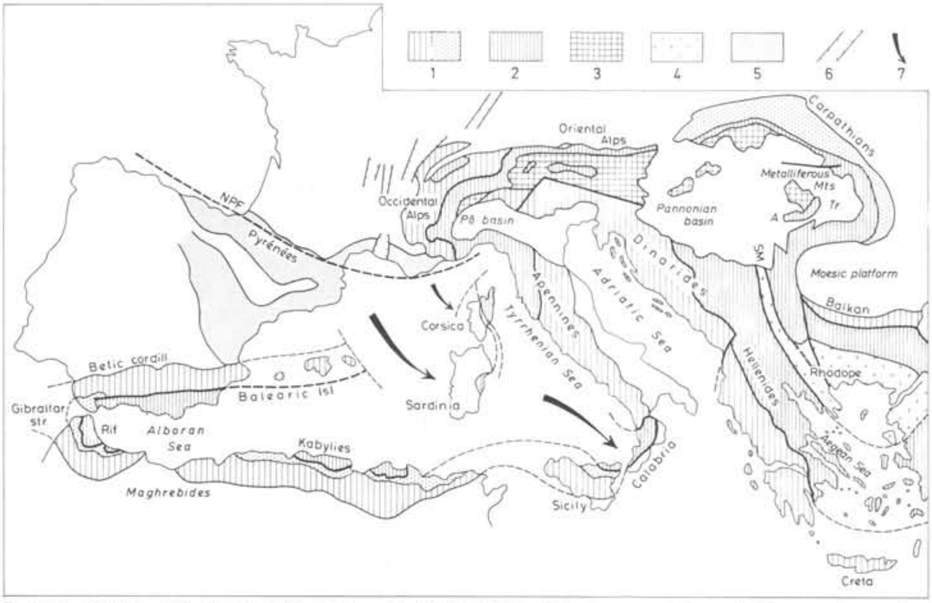


Figure 2. *The chains of Alpine Europe. 1: Externides (lines: mainly of Mesozoic material; dots: mainly of flysch material); 2: Internides; 3: Austroalpine zone; 4: Rhodope microcraton; 5: Intracontinental chains; 6: Rifts; 7: Continental displacements and sphenochasms (A: Apuseni Mountains; NPF: North Pyrenean fault; SM: Serbo-Macedonian massif; Tr: Transylvanian basin).*

Alpidic Branch

Alpidic Externides

The Betic chains (Fig. 2) comprise the Prebetic zone, nearest to the foreland cover, and a Subbetic zone which is entirely allochthonous. The Prebetic zone extends as far east as the Balearic islands, beyond which the continuity of the external Alpidic chain is broken by the recent opening of the Algeria-Provence gulf, associated with the sinistral rotation of the Corsica-Sardinia axis. The zone is scarcely represented in Sardinia and Corsica (the Corte slivers), but is seen again in the French subalpine chains (Occidental Alps - Fig. 2). These are flanked on the east by massive crystalline slivers ("external crystalline massifs"), covered mainly by Jurassic rocks.

In approaching the zone of hypercollision in Switzerland, the compression of externides becomes more intense, giving rise to the Helvetic and Ultrahelvetic nappes. In Austria, hypercollision is at its maximum, with externides reduced to minute slivers riding on the front of the nappes that are of a more southerly origin (Fig. 1).

Externides of a different nature are seen over a wide area in the Carpathians. Here, the zone of separation between externides and internides must have been one of crustal thinning, which acted, during compression, as a true intracontinental subduction zone in which most of the outer crust disappeared, leaving only the highest strata of the cover; these were detached and formed the flysch nappes (zone of the Moldavian nappes). Existence of an andesitic arc of Neogene age, in the north of the Pannonian basin (Fig. 3), and the initial thinning of the sub-Pannonian crust, an abortive marginal basin, provide evidence for this subduction zone.

A typical landscape in the Alpine externides: the Bornes massif (French Subalpine ranges). Foreground: La Tournette massif; background: Parmelan plateau and Glières syncline; all relief is in Urgonian limestones. This is a Mesozoic platform sequence in which the calcareous horizons control the morphology and clearly outline folds.

Alpidic externides end in the Balkan massif with the Prebalkan, which appears as the deformed southern extremity of the Moesic platform.

In summary, Alpidic externides comprise parts of the foreland and its cover, which is generally detached at the level of the Triassic evaporites. They also include an intracratonic

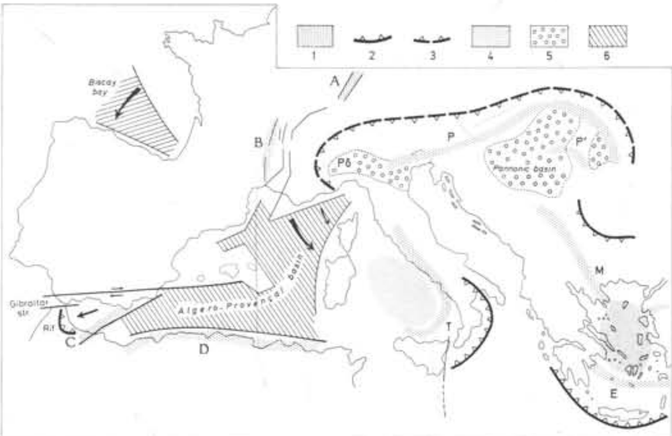


Figure 3. *Major neotectonic features of Alpine Europe. 1: Volcanic arcs (A: Rhine trench; B: French Massif Central; C: Alboran sea; D: North Africa; E: Aegean arc; M: Macedonian arc; P and P': Pannonian arcs; T: Tyrrhenian arc); 2: Subduction zones (E: Aegean; T: Tyrrhenian); 3: Intracontinental subduction zones of the Alpine and Carpathian externides; 4: Marginal basin or zone of crustal thinning; 5: Intramontane molassic basin; 6: "Neo-oceanic" gulfs of Algeria-Provence and the Bay of Biscay with indications of the corresponding continental opening movements.*

zone of subduction in which the basement of part of the foreland disappears, so that its cover becomes allochthonous. This makes tenable the hypothesis that the passage from externides to internides must have been a zone of crustal thinning or a rift.

The same contrast is found in sedimentary facies, with thin, mainly calcareous, neritic deposits toward the exterior, and more clayey deposits, typical of subsiding areas and deeper water, toward the interior (Subbetic, Ultrahelvetic and Moldavian series). The flysch facies may have been developed either in the Upper Jurassic-Lower Cretaceous (as in the Carpathians and the Prebalkan) or only in the Eocene (Ultrahelvetic). This strongly suggests the existence of a synorogenic trench developing ahead of a group of more interior nappes in the course of construction.

Alpidic Internides

Betic zones of the southern Spanish chains are made up of a number of units, each with Palaeozoic or granito-gneissic basement and a thin, mainly calcareous cover. While ophiolitic units are not found there, they do form the main part of the internides of Corsica, framed by slivers representing the ancient margins of a neo-oceanic trough.

In the Alps, both units coexist. The main part of the ophiolite-bearing units forms the Piemontese zone s.l. (or zone of "schistes lustrés"), the corresponding palaeogeographic province having probably tapered out toward the east. To the north, ophiolite-bearing units also appear locally in the Valais zone.

These two troughs thus enclose a sort of sialic microcraton, the Briançon zone (called the "Great St. Bernard nappe" by Swiss geologists). The European origin of this structure is obvious in the French Alps, where the Valais zone pinches out to the west. This complex of units, sometimes collectively called the Penninic group, then disappears to the east beneath the great Austroalpine thrust (the distorted margin of the Apulo-Adriatic promontory of the African craton), and reappears in the western Dacides near the Carpathians.

The continuation of (or the successor to) the Penninic is thus found again in front of the Dacides in the Pienides, but without ophiolitic units. Its overthrust character is also less pronounced because it lies to the east of the axis of the east Alpine hypercollision. Ophiolitic units do occur in what is probably the continuation of the Pienides in the Apuseni Mountains to the south of the Metalliferous Mountains (Fig. 2).

In the eastern Carpathians, the structure becomes complicated once again by two ophiolite-bearing zones, although there is no evidence to confirm correlation with the Valais and Piemont troughs. These two zones are the Transylvanian ophiolitic nappes (the continuation of the ophiolitic zones of the Apuseni Mountains), representing the external Dacic megatrough), and the more external ophiolite-bearing units (the Ceahlau and Severin nappes), representing the external Dacic megatrough.

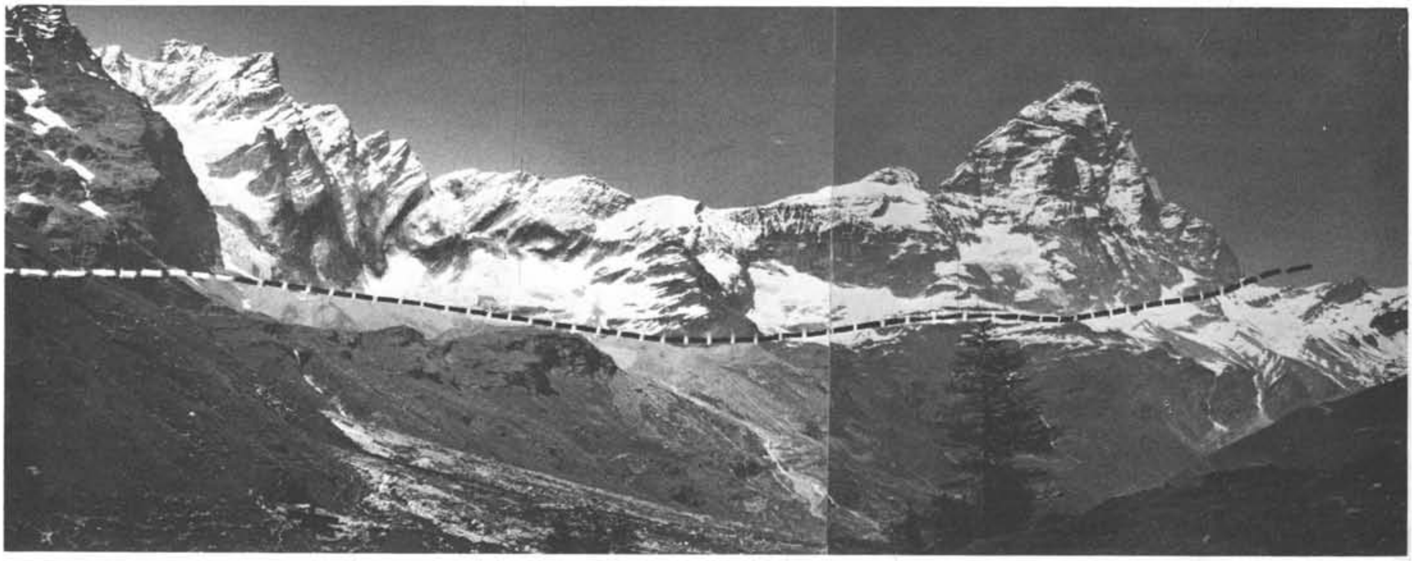
The remaining units of the eastern and southern Dacides between these two zones suggest a microcraton reminiscent of the Briançon zone in the western Alps. This element is the only one in the Balkan massif where ophiolitic units are lacking, as in the Betic chains at the western end of the European Alpine chain. Late Cretaceous vulcanism and "Laramic" granites, however, constitute a new feature.

In the European Alpidic arc, troughs with oceanic crust appear beyond the Betic sector, in Corsica. They are strongly developed in the Alps, but appear "sealed" in the Carpathians and especially in the Balkan massif. It is interesting to note that the maximum development of oceanic crust corresponds to the most strongly arched and overthrust belts in the European Alpidic system.

The history of the internides is complex. In Triassic time, a carbonate platform was established on a sialic basement. This platform was broken up at the end of the Triassic and in the Lias. Troughs with neo-oceanic crust then rapidly appeared during the "Mesogean Jurassic stretching", to be consumed by subduction from the end of the Lower Cretaceous (for the Piemont and internal Dacic troughs), or the Upper Cretaceous (for the Valais and external Dacic troughs). The first phase of tectonism led to widespread high-pressure metamorphism at around 80 Ma.

Thus, by the end of the Upper Cretaceous, the construction of the internal Penninic, the Austrides and Dacides was well advanced. A new and even more widespread tectonic phase started at the end of the Eocene (39 Ma), locally accompanied by high pressure metamorphism.

Two observations emanate from this history: (i) the tectonic phases corresponded to periods of acceleration of Atlantic spreading, and of collision between the European and African masses; and (ii) subductions which sealed the oceanic troughs



A typical landscape of the Alpine internides: looking north toward the Cervin (Matterhorn) from the Valtournache (Italy). The Cervin and the snow-covered mountains to its left belong to the old Paleozoic or Precambrian Austroalpine Crystallines, which here form part of the Dent Blanche nappe, thrust northward (along dotted line). The bottom of the valley (below the thrust) is formed of "Piemont schistes lustrés" (metamorphozed, ophiolite-bearing complex), strongly deformed as a result of a polyphase tectonic history. In terms of plate tectonics, the Cervin represents the continental African margin, thrust over the relicts of the oceanic Alpine (Tethyan) realm.

Middle Triassic bedded limestone containing Anisian ammonites, Val Camonica, northern Italy. (Photo courtesy E.T. Tozer)

did not have associated vulcanism or granitization as far east as the eastern Carpathians and the Balkan massif: here late Cretaceous "banatite arcs" may be linked with the subduction at the external Dacic megatrough. The reason for the lack of magmatism along much of the Alpidic branch is not yet clear.

Dinaric Branch

Dinaric Externides

Dinaric externides begin in North Africa with the external zones of the Rif and the Tell, which correspond to a subsiding area on the northern edge of the Sahara foreland where the cover was thinner and more neritic. The Rif-Tell sedimentary material, detached at the level of Triassic gypsums, forms nappes with southern vergence. Beneath them, parautochthonous units show transition facies to those of the Sahara foreland.

The Tell trough disappears beneath the Mediterranean, west of Tunis. It is interrupted by the recent structures of the Tyrrhenian sea, but is recognizable again in the Appennines of Marche, Umbria and Tuscany, where it is allochthonous to parautochthonous, and its foreland corresponds to the whole of southern Italy. The Abruzzi Campania mark the transition, as in the Tell, to Apulia, the Pouilles and the Ragusa plateau in Sicily - equivalents of the Saharan platform.

In the southern Alps (Bergamo Alps, Trentino, Friuli), external zones form a curve enveloping the extremity of the Apulo-Adriatic salient. The "miogeosynclinal" character of the trough becomes obscured here by the appearance of ridges and troughs that complicate the palaeogeography.

The allochthonous nature of the externides is also obscured: at most, the Mesozoic cover shows some superficial folds with southward vergence. But, on the other side of the peri-Adriatic line of fracture, this same material becomes the Austroalpine zone which overrides strongly toward the north. This peri-Adriatic fracture belt (its course marked by Oligocene granites) thus marks the limit, within the African margin, between autochthonous material of southward vergence and that of northward vergence. At depth it should also correspond to the southern limit of overthrust Penninic material.

In the Yugoslav Dinarides, externides form the Dalmation coast and the Karstic zone, sedimentation being of the neritic or reef type. It is only in the Hellenides that troughs of truly pelagic deposition reappear in the heart of this epicontinental calcareous complex (the zones of Ionia, the Pindus and Boeotia, separated by the Gavrovo and Parnassus ridges). Hellenic externides form the Pelopponese and Crete. Their tectonic style is that of thick thrust slices (in the Dalmation zone) or of folds with southwestern vergence (in the Ionian zone), all emplaced in the Neogene.

Dinaric Internides

From West to East, the Dinaric internides are represented first by a narrow North African fringe - the massifs of the Rif, where Betic units recur (the Betic-Rif arc raises the problem of linking the Dinaric and Alpidic branches), the Kabyle massifs of Algeria, the Peloritan massif of Sicily, and the Sila massif in Calabria. All of these are allochthonous, with a sialic basement and a dominantly calcareous cover overriding allochthonous Cretaceous-to-Palaeogene flysch whose palaeogeographic origins are not always clear. Deformation everywhere is prior to Upper Oligocene; Lower Miocene deposits unconformably overlie these eroded early Tertiary structures.

In the first group of massifs, the ophiolite-bearing units are lacking, as in the corresponding sector of the Alpidic branch. They are present in the Ligurian Appennines, where they form an allochthonous complex with eastward vergence, thrust over the Tuscan units. The deposits are identical to those of Corsica and the Penninic Alps, the Upper Jurassic radiolarites being in direct contact with the oceanic crust. There was thus only a single basin (the Piemont-Liguria basin); the eastward displacement of the Ligurian nappe over the external Appennine sector is a late feature of intra-Oligocene age. The Ligurian nappes and their foundations were then carried en bloc northeast in the Neogene, probably in association with the sinistral rotation of the Corsica-Sardinia axis (Figs. 2 and 3).

The ophiolite-bearing units are interrupted at the northern extremity of the Apulo-Adriatic spur: they pass beneath it and become confused with those of the Alpine Penninic and, like them, they disappear beneath the slab of the eastern Alps. They reappear east of the Adriatic in the internal Dinarides, where they are thrust over the externides (in the Serbian nappe), and then, further south, form two zones in the Hellenides which enclose the Pelagonian zone.

The northeastern (Vardar) zone is a continuation of the Yugoslav belt; the southwestern (sub-Pelagonian or Maliac zone is either a supplementary suture closing to the northwest, or a late (and frontal) fragment pinched off an ophiolitic nappe coming from the Vardar. If this latter hypothesis is accepted, it follows that the Vardar trough is the only single oceanic trough in the whole of the Dinaric and Hellenic system. The very extensive and intense synsedimentary vulcanism in the Upper Triassic (spilite-keratophyre type) and Upper Jurassic (potassic rhyolite type) adds complexity to the reconstruction of the palaeogeography. There was even andesitic to basaltic volcanism in the Oligo-Miocene in the Macedonian arc (Fig. 3), the significance of which is still obscure.

The Vardar zone is bounded to the east by the Serbo-Macedonian and Rhodope massifs (Fig. 2), both of which are partly sheared. They appear to be a crushed microcraton separating the Alpidic and Dinaric branches.

The internal Hellenic zones disappear beneath the Aegean sea, reappearing only in the Cyclades archipelago where the most southerly islands have become a true volcanic arc as a result of subduction, still in progress today.

To summarize, internides of the Dinaric branch comprise two quite different sectors: the ***Western Mediterranean***, in which the oceanic portion is not easily distinguished from that of the Alpidic branch. Formed in the Middle or at the beginning of the Upper Jurassic and closed by subduction during the Upper Cretaceous, this sector had no accompanying vulcanism on its immediate borders. The ***Eastern Mediterranean*** sector, in which the oceanic portion (whether divided into two or not) is separated from that of the Alpidic branch by the Serbo-Macedonian and Rhodope microcraton, appeared earlier than in the Upper Triassic and disappeared in the

Upper Jurassic, accompanied by intense vulcanism.

Gibraltar Arc

The two European branches of the Alpine system seem to come together in the Gibraltar arc in a way that has given rise to two interpretations. The arc is thought by some to be inherited from an originally arcuate palaeogeographic distribution, suggested by similarities between the Betic and Rif internal units, which became separated by the Straits of Gibraltar only in the Pliocene. This hypothesis is consistent with any reciprocal movement between the European craton (or more precisely of its Iberian annex) and the African craton, as is strongly suggested by new data on the opening of the Atlantic.

Others interpret the arcuate structure as having been formed in late Neogene age, when Africa moved toward Europe. The internal zones of the Betic would thus have been displaced to the west by a movement that was dextral, in relation to Spain, along the boundary between the internal and external Betic zones (Fig. 3), while the internal zones of the Rif were displaced along the Nekor fracture separating the Rif from the Algerian chains.

This hypothesis is supported by the fact that the contact between the internal and external Betic zones is indeed the line of a major strike-slip fault. Furthermore, the external Betic zones show no curvature at their western end and thus cannot be easily linked with North Africa. The allochthonous flysch that envelops the Gibraltar arc did not exist in the Betic sector before the Burdigalian (Miocene). They were emplaced at that time following a late-phase gravitational sliding, immediately prior to the shearing which formed the "Alboran block" comprising the Betic and Rif internal zones.

"Neotectonic" Arcs of Tyrrhenian and Aegean Seas

The Aegean arc (Fig. 3) is a curious structure among the younger chains of the eastern Mediterranean, and contrasts with sectors (such as the internal Hellenic zones) that have been closed since the Upper Jurassic. The "Alpine" structures of the Hellenides resulted from the subduction process that is continuing even at present, indicating that this region of the eastern Mediterranean is a relic of the Tethyan oceanic crust still not completely resorbed.

Three significant features are recognizable: (1) a deep trench (the Hellenic trench) reminiscent of the Circum-Pacific trenches; (2) an external sedimentary arc running from the Pelopponese to southern Turkey through Cyprus, Crete and Rhodes, containing detritus derived from the external Hellenic zones and not from sedimentary accretion above the subduction zone; and (3) an internal volcanic arc extending from the Saronic gulf to the Turkish coast, marked by island volcanoes of Poros, Melos, Santorini (Thera) and Nisiros.

The Aegean thus takes on the appearance of a nascent marginal sea: even the emergence of oceanic crust and the distribution of earthquakes in the Aegean are consistent with the model.

Difficulties arise from the fact that the data currently available on the crust of the eastern Mediterranean are somewhat contradictory. Some facts suggest that the Mediterranean crust is more continental than oceanic, implying possibly that the Aegean subduction is nearly complete (with all the oceanic crust having been absorbed), and that the African continental margin now reaches to the edge of the Hellenic trench. The Tyrrhenian arc is somewhat similar.

The Sicily-Calabria arc outlines a subduction zone with westward dip and peri-Tyrrhenian vergence which functions as a sedimentary arc, but again with detritus derived from the Calabrian segment of the externides. This interpretation is in agreement with the distribution of deep-seated earthquakes in the Tyrrhenian sea, which itself has the appearance of a marginal basin. The line of the volcanic arc is traced by the volcanoes of the Aeolian islands and their submarine homologues.

View SW down the Canon d'Arrazas, Ordesa National Park, Pyrenees, Spain: strata of Upper Cretaceous to Eocene age, forming part of the Mont Perdu nappe. (Photo courtesy W.C. Morgan)

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ENERGY AND RAW MATERIALS

The following series of sketches are devoted to the distribution and geological setting of the energy and mineral resources of Europe, as well as the history of their exploration and utilization.

European Mineral Wealth

by

A. Ziserman, J. Bertraneu and M. Jaujou

Introduction

Flint mines dug by Neolithic man on the frontiers of Belgium, Holland and Germany (Rijckholt) and in southern England are among some of the oldest known mines in Europe. When the art of metallurgy spread through the Middle East, mining activity expanded in Europe under the Phoenicians, Greeks and Etruscans. The Romans, and later the Saxons and the British as well, became leaders in the mining arts.

Most of the ancient mines are working today: Almaden (Spain), opened by the Phoenicians, is still the largest mercury mine in the world (Fig. 1); Laurion (Greece), whose silver helped to finance the birth of Athens, is still a centre of mining activity; Rammelsberg in Germany celebrated 1000 years of activity in 1968.

Highly industrialized western Europe is also an enormous consumer of ores and metals, and now depends largely on imports to satisfy its needs. The following table illustrates this.

RESERVES, PRODUCTION AND CONSUMPTION OF SOME KEY MINERALS IN WESTERN EUROPE (1977)[1]

Substance	Reserves[2]	Mining Production	Metallurgical Production	Consumption	Autonomy[3]
Aluminium	1.3 Gt	7.7 Mt baux.	3.5 Mt Al	3.6 Mt Al	30%
Copper	6.3 Mt Cu	0.33 Mt Cu	1.36 Mt Cu	2.74 Mt Cu	12%
Tin	300 Kt St	5.1 Kt Sn	29.8 Kt Sn	64.8 Kt Sn	8%
Iron ore	7 Gt Fe	91.1 Mt	-	176.8 Mt	52%
Lead	18 Mt Pb	0.49 Mt Pb	1.27 Mt Pb	1.39 Mt Pb	35%
Zinc	28 Mt Zn	0.98 Mt Zn	1.69 Mt Zn	1.56 Mt Zn	63%
Phosphates	very small	0.15 Mt	-	22.77 Mt	1%
Potash[4]	300 Mt K_2O	4.79 Mt K_2O	-	5.4 Mt K_2O	93%

t = tonne, K = Kilo = 10^3, M = million = 10^6, G = giga = 10^9
1 *Including Turkey and Yugoslavia.*
2 *Reserves are not always calculated on the same basis or with the same degree of precision from one country to another. For lack of accurate information, recovery has not been taken into account.*
3 *Autonomy is defined as the relationship between mining production and consumption.*
4 *For the year 1977-1978.*

In the last twenty years, there has been a definite renewal of mineral exploration in Europe, and several notable successes have been recorded.

Main mineral-bearing areas

In Europe, geological diversity from the Precambrian to the Alpine orogenies has assured a relative abundance of ores. The distribution of principal mineral deposits referred to in this summary is shown in Figure 1.

The Precambrian shield is exposed (as noted elsewhere in this issue) over large areas in Scandinavia; it is also found at very shallow depths in the Ukraine. It holds the very important iron ores of Kiruna (Sweden), Kursk and Krivoi Rog (U.S.S.R.) which, are of volcano-sedimentary origin. Polymetallic sulphide masses are found in Finland along the suture between two orogenies of different ages. Ultrabasic rocks there contain Cr, Ni, Cu, Co, Pt mineralizations. Anorogenic intrusions of Proterozoic to Permian age cut through the Baltic Shield. In the Kola Peninsula they are more than 40 km in diameter and are associated with important apatite and rare metal ore mineralizations.

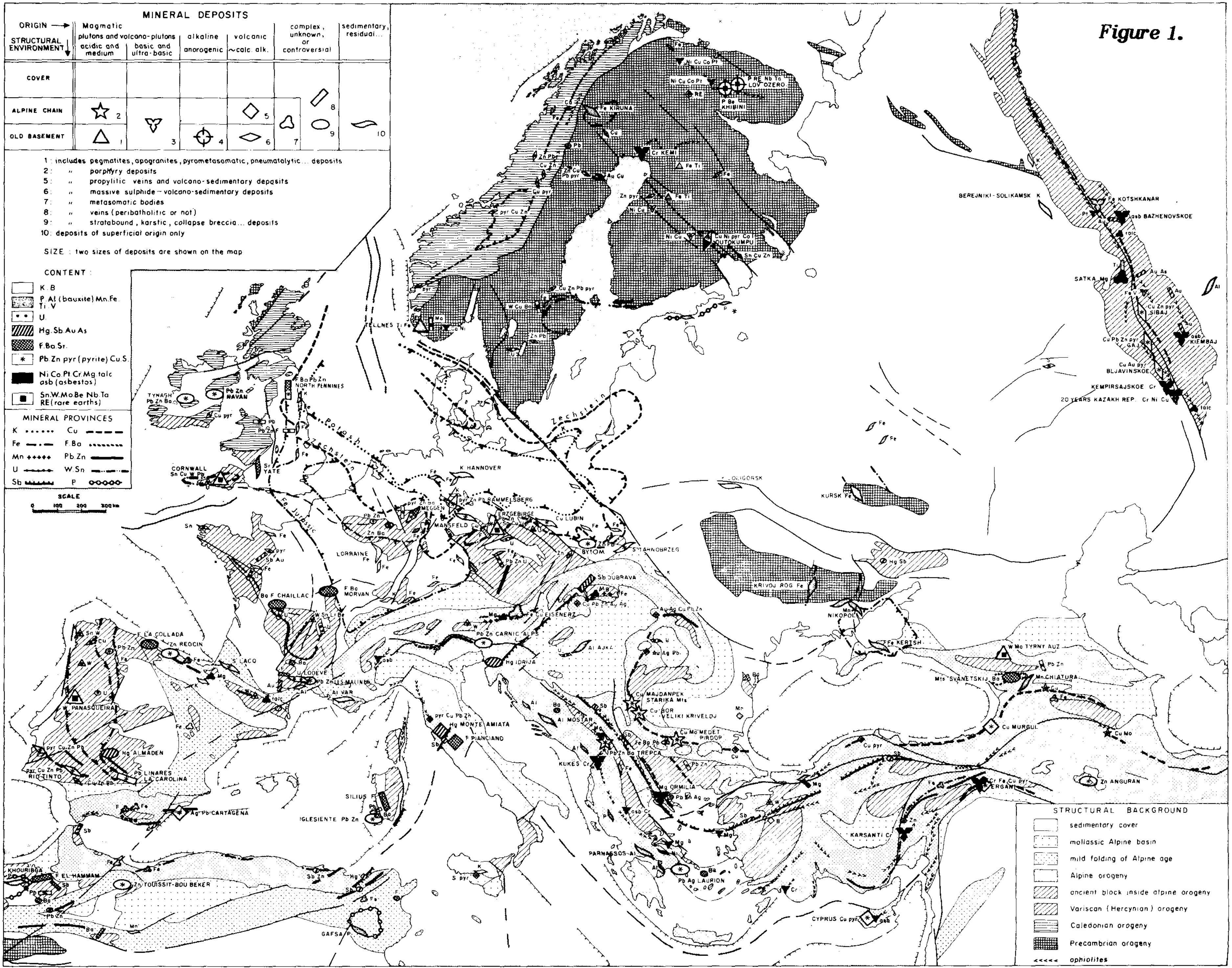
Old head frame at site of well-known former Orijarvi Pb-Zn mine, Finland. (Photo courtesy D.F. Sangster)

The Caledonian chain, draped around Norway and the northern British Isles and fringing the Baltic Shield, is characterized by its numerous polymetallic sulphide masses, many of which are of Ordovician age, though few are large enough to be of great importance.

The deposits in the western Variscan (Hercynian) chain are numerous. Some are associated with Upper Carboniferous intrusions, such as those of Cornwall and Erzgebirge (which have supplied most of the European tin), and the Iberian basement (which is dominated by the tungsten province of northern Portugal). Polymetallic sulphide masses are found in Portugal and Spain (Rio Tinto), across Germany (Meggen) to Moravia; the most important masses are of Devonian or Lower Carboniferous age. Pb, Zn and Cu veins, and uranium-bearing episyenites or stockworks were emplaced in Permian time. Still later, in the Triassic or even the Lias, veins and stratified deposits with F, Ba, Pb and Zn form a transition into the cover rocks.

The Urals have an abundance of copper, localized in polymetallic sulphide masses of Devonian age, as well as basic and ultrabasic rocks with Fe in the north and Cr in the south.

The Alpine chain bordering the Mediterranean is noted for its porphyry copper deposits in the Balkans and polymetallic deposits (with Cu, Pb, Zn, Sb, Hg, Au and Ag) associated with the Neogene propylitized vulcanics, which extend from Andalusia through Slovakia and the Carpathians to Iran and beyond. Basic and ultrabasic intrusions in suture zones host important Cr, Cu and As deposits, as in other orogenic


MINERAL DEPOSITS
ORIGIN
STRUCTURAL ENVIRONMENT
Magmatic
plutons and volcano-plutons
acidic and medium
basic and ultra-basic
alkaline
anorogenic
volcanic
~calc. alk.
complex, unknown, or controversial
sedimentary, residual...
COVER
ALPINE CHAIN
OLD BASEMENT
1: includes pegmatites, apogranites, pyrometasomatic, pneumatolytic... deposits
2: " porphyry deposits
5: " propylitic veins and volcano-sedimentary deposits
6: " massive sulphide - volcano-sedimentary deposits
7: " metasomatic bodies
8: " veins (peribatholitic or not)
9: " stratabound, karstic, collapse breccia... deposits
10: deposits of superficial origin only
SIZE: two sizes of deposits are shown on the map
CONTENT:
K.B
P.Al (bauxite) Mn.Fe. Ti.V
U
Hg.Sb.Au.As
F.Ba.Sr.
Pb.Zn pyr (pyrite) Cu.S.
Ni.Co.Pt.Cr.Mg talc asb (asbestos)
Sn.W.Mo.Be Nb.Ta RE (rare earths)
MINERAL PROVINCES
K
Cu
Fe
F.Ba
Mn
Pb.Zn
U
W.Sn
Sb
P
SCALE
0 100 200 300 km
Figure 1.
STRUCTURAL BACKGROUND
sedimentary cover
molassic Alpine basin
mild folding of Alpine age
Alpine orogeny
ancient block inside alpine orogeny
Variscan (Hercynian) orogeny
Caledonian orogeny
Precambrian orogeny
ophiolites
KIRUNA
LOVOZERO
KHIBINI
KEMI
OUTOKUMPU
TELLNES
NORTH PENNINES
NAVAN
TYNAGH
CORNWALL
YATE
Zechstein
K HANNOVER
RAMMELSBERG
MEGGEN
MANSFELD
ERZGEBIRGE
LUBIN
BYTOM
LORRAINE
CHAILLAC
MORVAN
DUBRAVA
EISENERZ
CARNIC ALPS
IDRIJA
LA COLLADA
REOCIN
S. LACQ
LODEVE
LES MALINES
VAR
PANASQUEIRA
ALMADEN
LINARES
LA CAROLINA
RIO TINTO
CARTAGENA
MONTE AMIATA
PIANCIANO
IGLESIENTE
SILIUS
MOSTAR
MAJDANPEK
BOR
VELIKI KRIVELJ
TREPCA
KUKES
PIRDOP
ORMILIA
PARNASSOS
LAURION
KHOURIBGA
EL HAMMAM
TOUISSIT-BOU BEKER
GAFSA
KRIVOJ ROG
NIKOPOL
KURSK
KERTSH
TYRNY AUZ
CHIATURA
MURGUL
ANGURAN
ERGANI
KARSANTI
CYPRUS
BEREJNIKI-SOLIKAMSK
KOTSHKANAR
BAZHENOVSKOE
SATKA
SIBAJ
KIEMBAJ
GAJ
BLJAVINSKOE
KEMPIRSAJSKOE
20 YEARS KAZAKH REP.

View to north of Cerro Colorado pit and mineral processing plant, Rio Tinto, Spain. (Photo courtesy R.V. Kirkham)

regions. Metasomatic masses of iron (hematitic or sideritic), magnesite and talc are common. Palaeozoic or Precambrian carbonate rocks caught up in the Alpine chains are found in many cases (such as at Laurion, Greece and Anguran, Iran) to contain large deposits of Pb, Zn, Ba.

The strata of the sedimentary cover, contrary to generally held views, contain large mineral deposits. For example, the Permian was an important period for the formation of the potash near Hanover (F.R.G.) and Soligorsk (U.S.S.R.) and for copper at Mansfeld (F.R.G.). The Jurassic is well known for its oolitic iron ores of northern Europe, the largest deposit of which is in Lorraine, France.

In Cretaceous times, bauxites were formed from Spain through to Turkey; the Black Sea manganese (Nikopol) is of Eocene age and is similar to deposits at Varna (U.S.S.R.) which are of sedimentary volcanic origin; the Maghreb phosphates of north Africa are of the same period. Sulphur, potash and uranium were deposited in Alpine molassic basins at different times during the Tertiary era.

Conclusion

A detailed analysis of the distribution of deposits would show that around the margins of the orogenic belts that constitute the framework of this summary, mineral concentrations of Europe are in many cases arranged in a fairly geometrical pattern. They occur in complexes with metallic zoning which encircle the great prominent structures. They seem to point to geochemical characteristics of particular regions of the earth's crust, for which orogenies have acted merely as successive mobilizers of a fundamental inheritance. Here, the concept of the metalliferous province (L. de Launay, 1913) finds its true expression.

Europe can be divided in two by a great NW-SE line of fracture, with the Urals and the Scandinavian shield at the top on the right, and the Alpine chain and Variscan Europe below and to the left. This is the Tornquist line, as referred to by A. Simonen in Figure 2 of this issue of EPISODES. Another line, running from Tunisia to Slovakia, divides the lower part. Its course is marked by mercury and antimony deposits of very recent date. To the west lies Variscan Europe with its potash-bearing and copper-bearing Permian and iron-bearing Jurassic cover. To the east, the Alpine chain is rich in ores associated with ultrabasic rocks (Cr, Cu, pyrite, asbestos, Mg), or with volcanoes or plutons (Cu, Pb, Zn, Ag, Au, Sb) of Andean cordillera type. Recent work by Routhier (1977) and others shows that distributions worked out for each metal on a detailed scale greatly assist in the accurate selection of future targets for mineral exploration.

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Mine site of volcanogenic massive sulphide ore body (chiefly copper), Avoca Mine, Ireland. (Photo courtesy D.F. Sangster)

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Western European Oilfields: An Outline

by

A. Perrodon

Oil has been produced in Western Europe since the Middle Ages and, at the industrial level, since the end of the 18th century, though it was only in the 1960's, with the discovery of the giant gas fields of Holland and the southern North Sea that its potential was fully appreciated. It is clear now, after more than a century of onshore effort, that the North Sea, and in particular the part between British and Norwegian waters, will reap the greatest rewards.

The sedimentary formations of interest in the search for petroleum cover approximately 3.6 M km^2, almost 2 M (million) being onshore and 1.6 M offshore in the Atlantic and the Mediterranean. 4.4 Gt (thousand million tonnes) of oil and more than 5,500 Gm^3 of gas have been found in this area; 3.7 Gt of the oil are situated in the North Sea, though of the total 4.4 Gt, only 640 Mt have been produced so far.

Reserves are contained in some 500 fields across 20 petroleum provinces. Amongst them 15 are categorized as "giant" fields (> 70 Mt or equivalent in gas), and two-thirds of these are oil-bearing; all of them are situated in the North Sea, with the exception of the three gas (and condensate) fields of Groningen, Lacq and Malossa.

These petroleum provinces are found in formations of Carboniferous to Pliocene age deposited between the Caledonian, Hercynian and Alpine orogenies.

Figure 1. MAIN SEDIMENTARY BASINS AND OIL PROVINCES OF THE WESTERN EUROPE

Basins of the Carboniferous

In the British Caledonian region, the Carboniferous formations of the East Midland basin (Fig. 1) constitute a very minor province of 12 small fields, the total initial reserves of which do not exceed 3 Mt. In northern Germany, the more developed Carboniferous contains (at Rehden in particular) gas deposits of the order of 15 Gm^3.

Permian basin

The most important gas reserves are found in the vast Permian basin stretching from southern Great Britain to Poland. The Rothliegende detrital deposits of fluviatile and aeolian origin, supplied by Westphalian Coal Measure beds and effectively capped by Zechstein evaporites, constitute a gas province of major importance. The initial reserves of the basin are estimated at 3,800 Gm^3, distributed for the most part in the following giant fields: Groningen, (2,650 Gm^3) in the Netherlands, and Leman (300 Gm^3), Indefatigable (125 Gm^3) and Hewitt (100 Gm^3) - all in the British zone of the southern North Sea.

The Zechstein can be productive when it has an algal or karstified carbonate facies resulting from ancient submarine highs. Consequently, the Zechstein is a gas reservoir containing almost 200 Gm^3 among 40 deposits in northern Germany; it is also the principal oil reservoir of the Auk and Argyll fields of the North Sea.

Basins of the Mesozoic

The Triassic and Jurassic seas covered the greater part of Western Europe, forming vast cratonic basins in which individual troughs of subsidence, with a more or less North-South orientation, were formed, generally displaying excellent petroleum potential.

Mediterranean

There is a vast mesogean Mesozoic basin in the Mediterranean area, characterized by Triassic source rocks and mainly carbonate reservoirs, whose age depends on that of the caprock. The fields occur in different zones:

- *South-West Sicily*, with the heavy oil fields of Ragusa and Gela (40 Mt initial reserves);
- *Middle Po River Valley* with the field of Malossa, producing from Triassic dolomite capped by Cretaceous limestones and Oligocene marls (50 Gm^3 gas and 40 Mt liquid hydrocarbons);
- *Periappennine zone*, usually producing heavy oil from Cretaceous carbonate reservoirs with a Miocene caprock. Notable fields include David, Rospo Mare, and Maria Mare - a zone which could contain reserves of up to 300 Mt;
- *Offshore Ebre delta, Spain*, also producing from the Cretaceous and in some places from the base of the Miocene. The caprock is formed by transgressive Miocene formations; one-third of total reserves (30 Mt) are in the Amposta field.

North Sea/Germany

In the Nordic area, there are several Jurassic and Cretaceous basins with a N-S orientation. These basins are affected by deformations such as Cimmerian horsts and grabens capped by Kimmeridgian transgressive shales. The different zones of petroleum production share the common characteristic of having originated from Jurassic source rocks.

Important zones include the:

- *Gifhorn trough* in West Germany, containing initial reserves of 30 Mt among 50 deposits;
- *Hague graben*, slightly folded, producing oil from the lower Cretaceous (25 Mt);
- *Viking and Central grabens* of the North Sea, producing from the Liassic and Dogger, capped by Kimmeridgian shales (Statfjord, Brent and Magnus fields), from Eocene-Palaeocene sands (Frigg, Forties) in the northern area, and from Upper Cretaceous chalk (Ekofisk) in the central area.

This province has reserves in the region of 3 Gt oil and 12 000 Gm^3 gas, mostly in ten giant fields.

Other basins

Between these two major areas, there extends a series of Mesozoic cratonic basins in which the principal zones of interest are the Jurassic and the Lower Cretaceous.

In northern Germany, the province of Ems is of particular interest, situated astride the Germany-Netherlands border; 40 Mt of petroleum have been discovered in Lower Cretaceous sandstones, half of which lie in the Dutch fields of Schoonebeek.

The Paris Basin, producing oil from Dogger carbonates and from Lower Cretaceous (Valanginian and Hauterivian) sands, contains reserves of 10 Mt among 20 deposits.

Production in the Aquitaine Basin in France is mainly from two zones in the Lower Cretaceous situated on the edge of the platform - the Parentis province in the North (45 Mt oil), and the Lacq zone (about 300 Gm^3 gas).

Tertiary Basins

The Alpine orogeny was accompanied by the formation of a number of basins which complement those already in existence. Amongst the most important are the following three Neogene provinces:

- *Vienna Basin, Austria* where reserves of 100 Mt oil and 100 Gm^3 gas have been discovered in 40 deposits, the major part being concentrated in the Matzen field;
- *Yugoslav section of the Pannonic Basin* with initial reserves of roughly 100 Mt oil and 50 Mm^3 gas;
- *Po plain basins and edge of the Appennine area*, particularly rich in gas (roughly 350 Gm^3).

Conclusion

Western Europe is on the one hand an old petroleum region, with many onshore fields being close to exhaustion; on the other hand however, it is a new region of offshore potential. The most important province, that of the North Sea, was only discovered in the 1960's. New deposits continue to be found onshore especially in deeper horizons, while other offshore basins remain to be explored. Given this and the regional economic conditions, Europe offers strong potential for future exploration.

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Geothermal Energy in Western Europe

by

J. Lavigne

Although industrial application of geothermal energy dates only from the beginning of the present century, use of energy from this source has greatly increased in recent years, both at the high energy level - in supplying steam to power stations, and at the low energy level - in supplying warm water for central heating and argicultural use.

Steam is generated in those regions of Europe with current or recent magmatic or volcanic activity. Sources of warm water are much less narrowly localized. Of greatest economic interest, however, are the deep sedimentary basins, where waters in aquifers are heated to high temperatures and can be used directly for heating of dwellings.

Volcanic regions

Regions of active volcanism are found in southern Europe, chiefly in Greece and Italy, as well as in Iceland and the Azores.

Italy today has an installed capacity of more than 420 MW, representing an annual output of the order of 3000 GWh. The source-aquifers lie in the "borax-bearing region" of Tuscany (the fields of Larderello, Castelnuovo, Serrazzano, Lago, Travale), with an installed capacity of 400 MW, while in the Monte Amiata region the installed capacity is 20 MW. Exploration is being pursued in the whole of the pre-Appennine zone from Pisa in the north to Naples in the south, which includes the regions of Travale, Monte Volsini, Monte Cimini, Monte Sabatini, Naples, Volterra.

In Greece, a potential source has been discovered on the island of Melos and evaluation is continuing. In Iceland small power stations (7 MW) are working in the Reykjavik area. Exploration is active in France (particularly in the Mont Dore area) and in the Azores.

Sedimentary basins

Major basins recognized in the past as being potentially interesting to petroleum exploration are currently being explored again in several countries for sources of sufficiently warm water stored in deep-seated aquifers. In France there are four working installations in the Paris Basin (Melun l'Almont, Melun les Courtilleraies, Villenneuve-la-Garenne and Creil), and three more in the Aquitaine basin (Blagnac, Mont-de-Marsan, Dax). Other plants are under construction in both regions and also in the Alsace trench. Current production supplies heat to some 15 000 dwellings.

While similar installations using hot water have long been used in Hungary and Iceland, potential sources are being evaluated in most of the sedimentary basins of Spain, Italy, Yugoslavia, Switzerland, Germany, the United Kingdom, Netherlands, Belgium, and Denmark.

Geothermal steam plants at Larderello, Italy. (Photo courtesy A.M. Jessop)

ABOUT THE AUTHOR: Jacques Lavigne has spent much of his professional career in petroleum research, having been chief geologist in charge of prospecting in the European part of the North Sea for the company Régie Autonome des Petroles. He now heads the program planning section in the BRGM, France.

Uranium in Western Europe

by

J. Dardel

Although the element uranium was only named in 1789 (by Klaproth) and was first isolated in metallic form in 1841 (by Péligot), it has been used in Europe since the Middle Ages. Miners in Saxony who worked silver in the Middle Ages had identified pitchblende, or uranium oxide, while potters concocted from it a pigment which gave a glistening greenish-yellow tint to glass and pottery.

Yet it was not until 1904 that the working of uraniferous minerals on an industrial scale began in Portugal and Czechoslovakia for the production of radium. In Europe, mining began again soon after World War II for the production of uranium as a fissile material.

Resources and Production

Western Europe's uranium resources[1] represent about a tenth of world resources, or 486 950 tonnes of uranium (tU) recoverable at a cost of less than $130 per kilogram of uranium. These resources were of the same order of magnitude in 1978 as the cumulative world production (532 700 tU) during that year.

Production in Western Europe in 1978 was 2,513 tU. In 1978 and 1979, the Federal Republic of Germany, Spain, France and Portugal were amongst the producing countries and at the end of 1978, their combined resources were 142 150 tU.

[1]That is, those of F.R.G., Spain, Finland, France, Italy, Portugal, United Kingdom, Sweden, Switzerland and Yugoslavia.

Nevertheless, production for the whole of Europe in 1978 may have amounted to about 10 000 tU (U.S.S.R., France, Czechoslovakia, Hungary, Romania and the German Democratic Republic being the main producing countries). This may have represented about a quarter of world production (exclusive of China).

Main Deposits

The world's main uranium-bearing provinces occur in Precambrian shields (South Africa, Australia, Canada) or in the sedimentary cover of Precambrian shields (U.S.A., Niger). In Europe, though large quantities of uranium are known to exist in the Cambrian black shales of the Baltic Shield, vein deposits are more particularly associated with the Moldanubian granites of the Variscan orogeny, while deposits in the enclosing sedimentary cover are in the Permian-to-Palaeogene detritus derived from erosion of the Variscan chain.

Europe's present production and reserves of uranium are for the most part in vein deposits associated with granitoids, deposits in sediments (grits, lutites and carbonaceous shales), and those related to volcanic rocks in vulcano-sedimentary sequences.

Vein Deposits

At present, vein deposits worked in the Variscan province of Europe are associated spatially with granitoids being either enclosed in the granite itself (intragranitic) or in volcanic or metamorphic rocks in the aureoles around granite plutons (perigranitic).

Intragranitic vein deposits occur in the Iberian Meseta (Urgeiriça and Borrega in Portugal), in the Armorican massif and the Massif Central (La Commanderie, l'Escarpière; le Bernardan, Bellezane, Fanay, le Fraisse, Margnac, Peny, Hyverneresse, Le Cellier, Les Pierres Plantées) and in the Black Forest (Menzenschwand).

The Fanay and Margnac deposits in the western Massif Central are in a muscovite-biotite leucogranite. The mineralized zones vary in form from a linear type with vein infillings to a columnar type. "Linear" mineralizations are contained in tectonic blocks about 1 m thick, mostly formed of phyllites. They occur either as a single vein-infilling or in the "threads" of stockworks. Columnar mineralizations impregnate "pipes" of vacuolar rock formed by dissolution of quartz by solutions from the enclosing leucogranite. These are locally called episyenites.

Primary uranium mineralization is mainly pitchblende, accompanied in many cases by coffinite and/or black oxides with scattered iron sulphides.

Perigranitic vein deposits occur in the Iberian Meseta (Fé and El Perdrigal in Spain, Nisa in Portugal), in the Massif Central (Les Bondons, France) and in the Bohemian Massif (Pribram and Jachymov in Czechoslovakia, and Aue in G.D.R.). They have the following in common:

- mineralization is in Proterozoic to Palaeozoic rocks close to the contact with a leucogranite of Variscan age (maximum distance from the contact is 1 km in the Iberian Meseta and 2 km in the Bohemian Massif);
- presence of pyritous and carbonaceous schists and lenses in the metasedimentary sequence in which the deposits occur is characteristic;
- mineralization appears to have impregnated zones of cataclasis or crushing at the intersection of old clay-filled fault fissures or of certain facies rich in pyrite and carbonaceous material (Pribram) or in amphibolites (Jachymov).

The nature of the metasediments, their degree of alteration and the geochemistry of the mineralization vary from one district to another. The uranium itself is either in the form of secondary minerals in the schists of El Perdrigal and Fe (within a depth of 50 m), or in the form of pitchblende in the gneisses, amphibolites and micaschists of Jachymov and Aue, accompanied by minerals containing Bi, Co, Ni and Ag, or in the shales and slates of Pribram, where ores of Pb, Zn, Ag and Au are also worked nearby.

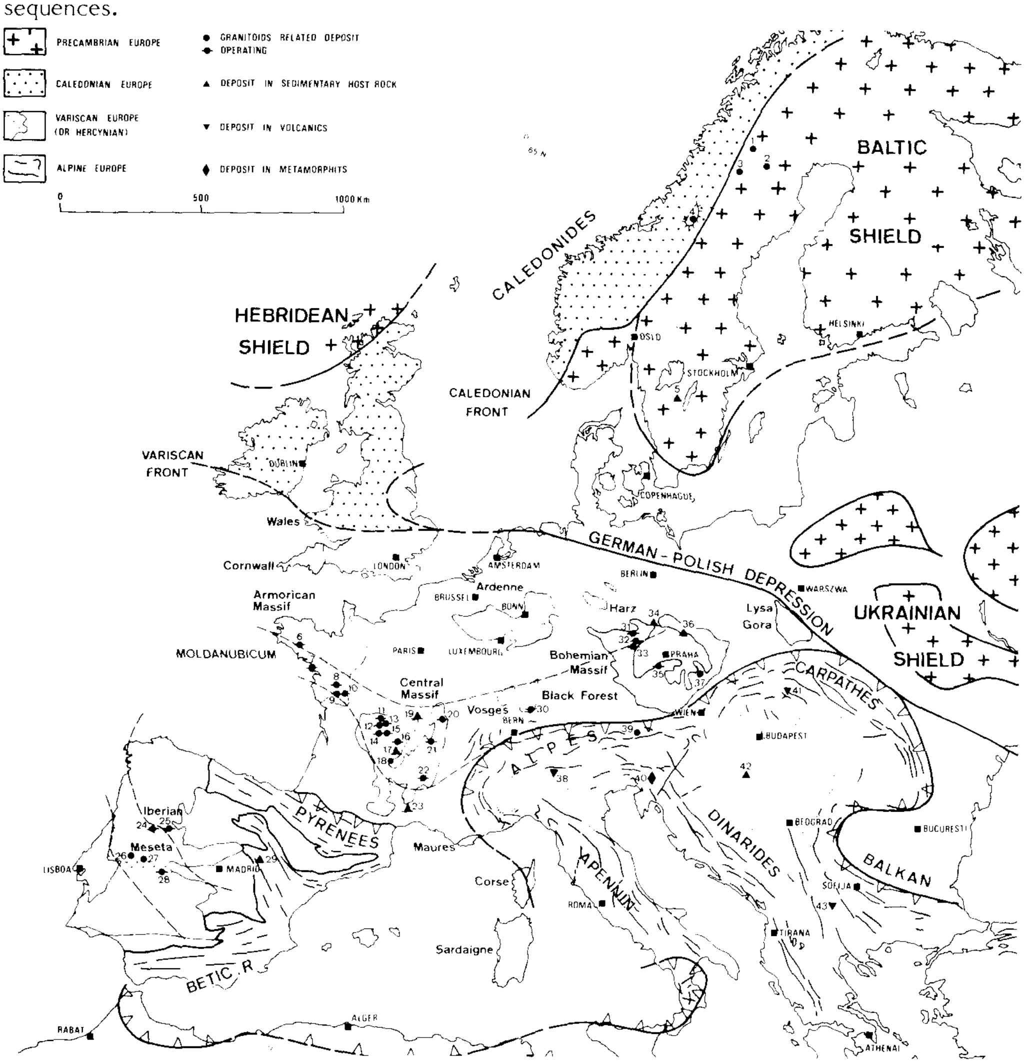

Figure 1. Main uraniferous deposits in Europe: Sweden: 1. Pleutajokk 2. Ravaberget 3. Dubblon 4. Hotagen 5. Ranstad; France: 6. Pontivy 7. Pennaran 8. Ecarpière-Le Chardon 9. Beaurepaire 10. La Chapelle Largeau - La Commanderie - La Dorgissière 11. Le Bernardan 12. Le Brugeaud 13. Bellezane 14. Margnac-Peny 15. Fanay - Le Fraisse 16. Hyverneresse 17. St-Pierre du Cantal 18. Bertholène 19. Cerilly 20. Grury 21. Bois - Noirs 22. Le Cellier - Les Pierres Plantées 23. Mas Laveyre; Portugal: 24. Urgeirica; Spain: 25. Fe; Portugal: 26. Nisa 27. Tarabau; Spain: 28. El Pedrigal 29. Mazarete; F.R.G.: 30. Menzenschwand; G.D.R.: 31. Aue; Czechoslovakia: 32. Jachymov district 33. Horni Slavkov; G.D.R.: 34. Koenigstein; Czechoslovakia: 35. Pribram district 36. Hamr 37. Rozna-Olsi; Italy: 38. Novazza; Austria: 39. Forstau; Yugoslavia: 40. Zirovski Vrh; Czechoslovakia: 41. Huta -Muran; Hungary: 42. Mecsek; Yugoslavia: 43. Zletovska Reka.

The Fanay and Fraisse mines (Haute-Vienne) in northern Limousin (France). The Fanay mine has 50 km of workings to a depth of 300 m. (Photo courtesy Commissariat à l'Energie Atomique, France)

Sedimentary Deposits

Deposits associated with sedimentary rocks occur in the Cambrian carbonaceous shales of Ranstad in southern Sweden, in the Permian lutites and silts of Lodève (France) and in Permian to Palaeogene grits elsewhere in Europe. At Ranstad, the uranium is stratiform (2.5 to 4 m thick) in an Upper Cambrian bituminous shale horizon. The ore is of low metal content (average 0.03% U), with 22% carbonaceous material and 13% pyrite, but the volume of the ore is very large (300 000 tU).

At Mas Laveyre in the Permian basin of Lodève, the mineralized sequence is characterized by fine-grained rhythmic sediments of marsh to lagoonal facies (arkosic carbonate silts, bituminous laminae, green argillites) or of floodplain facies (red clayey silts). Mineralization occurs in layers or in masses in fault zones; uranium is present in pitchblende or coffinite, or in association with carbonaceous material.

Other deposits occur in sandstones of (i) Permian age - at Lombre (France), Mecsek (Hungary), and Zirovski Vrh (Yugoslavia); (ii) Triassic age - at Mazareta (Spain); (iii) Cretaceous age - at Hamr (Czechoslovakia) and Koenigstein (G.D.R.); and (iv) Palaeogene age - at St. Pierre du Cantal (France).

At Lombre, mineralization occurs in former meandering river channels, especially at the transition between downcutting sandstones and carbonaceous silts. The uranium is in pitchblende and coffinite accompanied by pyrite, marcasite and carbonaceous material. At St. Pierre du Cantal, mineralization is in Oligocene arkosic sands channelling into the lutites of a former floodplain, and is commonly restricted to zones rich in carbonaceous material at the base or top of sand bodies. The uranium, which occurs mainly as a secondary mineral, is accompanied by minerals containing V, P, Se and As.

Volcanic Deposits

Deposits associated with vulcanites are present in Alpine areas, in particular at Novazza in the Bergamo Alps (Italy), at Huta-Muran in the Carpathians (Hungary), and at Zletovska Reka between the Dinarides and the Macedonian massif (Yugoslavia). At Novazza, mineralization is in an acid ignimbrite of a Permian sedimentary volcanic formation. Pitchblende is accompanied by zinc, lead and molybdenum mineralization. At Novoveska Huta-Muran in the Spis-Gemer massif, mineralization occurs in tuffs, lutites and sandstones within a Permian sedimentary volcanic formation. Pitchblende is associated with copper and molybdenum minerals. Mineralization at Zletovska Reka is in Cenozoic dacitic and andesitic vulcanics in which the uranium occurs as black oxides associated with pyrite.

Operational mines at present are mainly in the Variscan province and in particular in the Moldanubian zone. Recent exploration has also revealed deposits of possible economic potential in the Precambrian province. For example, the Arvidsjaur and Arjeplog occurrences in northern Sweden have striking analogies with the Precambrian deposits of Beaverlodge, Canada.

Europe's move toward independence in energy necessitates an increase in production of uranium from the region's resources, and hence, vigorous exploration to locate the undiscovered reserves. In fact, it is only if the current rate of exploration is maintained through the eighties that the rate of production will keep pace with European demand predicted for the year 2000.

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ABOUT THE AUTHOR: **Jacques Dardel** has been with the uranium exploration division of the French Commissariat à l'Energie Atomique (Atomic Energy Commission) since 1954, and has served on assignments in Madagascar, Turkey, Africa and Canada. In charge of the exploration and development of Cluff Lake mine in Saskatchewan, Canada from 1967 to 1975, he was with the Fanay mine in Haute Vienney, France from 1975 to 1978.

EDITOR'S NOTE: Some of the preceding articles were originally submitted in French. The task of translating them into English was undertaken by **Richard V. Melville**, to whom EPISODES owes a special vote of thanks. A palaeontologist, Dr. Melville is currently Secretary of the International Commission on Zoological Nomenclature. He retired as an Assistant Director of the Institute of Geological Sciences (U.K.) in 1974. From 1961 to 1965, Dr. Melville served as Scientific Counsellor at the British Embassy in Paris. *(Copies of the original French texts are available, on request, from the IUGS Secretariat, Room 177, 601 Booth Street, Ottawa, Canada K1A 0E8.)*

A word of thanks also to **Dr. Henri J. Radier**, exploration manager at Elf Aquitaine in France, who helped to assemble the articles on energy in the last series of sketches.

Richard Melville

Henri Radier

News In Brief. . .

26th International Geological Congress: Highlights

The Occasion: A Centenary

When Paris hosted the first International Geological Congress in 1878, it started a tradition of quadrennial gatherings of geologists from all over the world - to share ideas and exchange information in wide-ranging interdisciplinary scientific dialogue.

Fittingly, the 26th session of the Congress, under the sponsorship of IUGS, returns to Paris to celebrate the centenary of the IGC and to pay tribute to Europe in general for its significant contributions to the origin and evolution of earth science studies.

To mark the occasion officially on a national scale, the French post office will be issuing a stamp dedicated to geology.

(For a historical account of the origin of the IGC, see Prof. F. Ellenberger's article "The First International Geological Congress, Paris, 1878" in EPISODES, Vol. 1978, No. 2, p. 20-24.)

The Setting: Paris

"The last time I saw Paris,
her heart was warm and gay,
I heard the laughter of her heart
in every street café ......"

The sheer fun of Paris needs no introduction. It has been echoed in lyrics such as Oscar Hammerstein's for centuries, and its magic will undoubtedly continue to delight visitors for centuries to come.

The many artistic, cultural, intellectual, social, gastronomic and other diversities of Paris are well documented. Maps, guide-books and descriptive literature of every kind will be readily available in most hotels and bookstores, at the International Centre of Paris and the Congress itself, which will operate in the registration area both a travel agency and a general information counter to advise participants on shows, tours and trips, and to facilitate the purchase of tickets. The 26th IGC Secretariat is also planning to issue a list of recommended restaurants.

In short, even the most die-hard "all work and no play" geoscientist is sure to be tempted in Paris!

The Site: International Centre of Paris

Almost all of the Congress meetings and functions are scheduled to take place under one roof - that of the **International Centre of Paris** (also called the **Paris Convention Centre**, or **Palais des Congrès** in French). Located in the Place de la Porte Maillot ("Porte Maillot" metro stop) on the edge of the Bois de Boulogne, the Centre is just five minutes from the famous Arc de Triomphe and the Champs-Elysées.

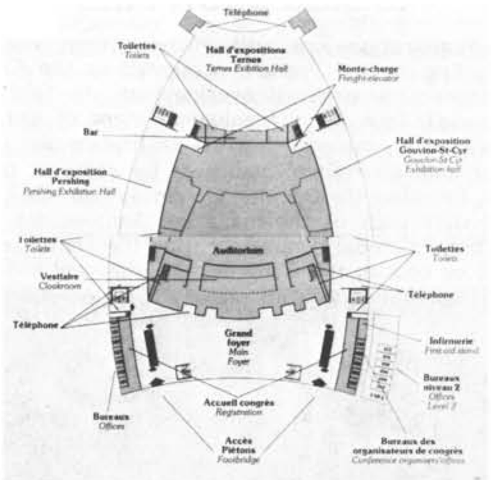
An elegant convention complex, unique in Europe, it can easily accommodate 5,000 people and boasts every modern technological facility. The Centre has an auditorium/amphitheatre which seats over 4,000 people (the permanent headquarters of the Paris Orchestra), conference and committee rooms of varying sizes, exhibit halls, offices, restaurants, bars, discothèques, four cinemas, 80 boutiques with a host of other amenities (pharmacies, banks, hairdressers, tourist agencies) spread on two levels, a gymnasium, swimming pool and saunas. The 34-storey (1,000 rooms) Concorde-La Fayette Hotel is attached to the Centre, while the Hotel Meridien stands "next door" to it.

Many of the conference rooms are equipped with six-language simultaneous translation facilities. Congress organizers have made arrangements for simultaneous English/French and French/English translation during the Colloquia and the Congress Council meeting, though presentations during the latter (and during the Sections) may be made in any of the six official languages of IUGS - English, French, German, Italian, Russian or Spanish. Although no simultaneous translation will be available for the Section meetings, Section abstracts will be printed in the six above-mentioned languages, while the printed Colloquia papers will appear in both English and French.

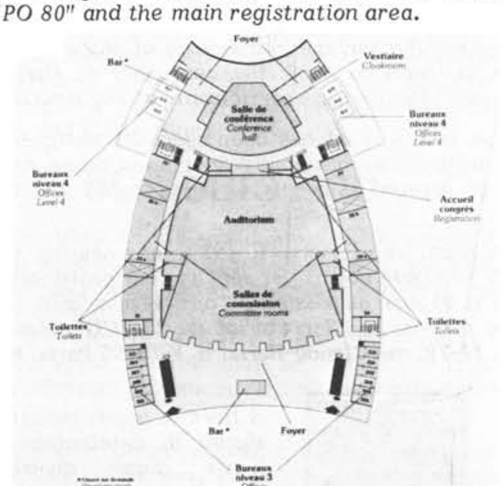
All of the scientific meetings will take place in the Centre, including the Opening Scientific Session, the Sections and Colloquia, the Special Symposium on Geodynamics, and the various meetings of the scientific associations and societies. Registration for both the Congress and the different activities and excursions planned under the social, accompanying members', and juniors' programs will also take place at the Centre, as will the Festival of Scientific Films. It is anticipated that **Mr. Giscard d'Estaing,** President of the Republic of France will participate in the Closing Ceremony, which will take place in the Centre's auditorium.

The Opening Ceremony of the first General Assembly and the Reception immediately following this Ceremony will take place in the historic and expansive Grand Palais on Avenue Winston Churchill ("Champs Elysées/Clemenceau" metro stop). The Minister of Industry, **Mr. André Giraud** will take part in the Ceremony.

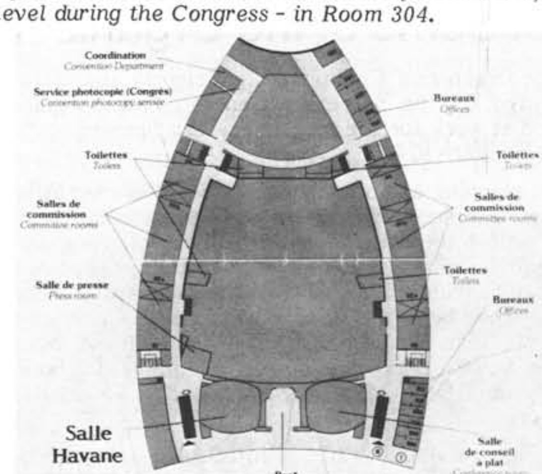
The modern International Centre of Paris offers two levels of boutiques, shops, amenities and entertainment facilities. (Photo courtesy Palais des Congrès)



Level 1 of the Palais des Congrès includes an impressive auditorium/amphitheatre - the core of the Centre, where the Congress' Opening Scientific Plenary Session will take place on July 8, as well as the Closing Ceremony on July 17. Each of the three main levels (1, 3 and 5) consists of two horseshoe shaped storeys, the second being a "deck". Level 1 will house the Congress' scientific and technical exhibition - "GEOEXPO 80" and the main registration area.



Level 3 contains many of the smaller committee rooms, as well as the Salle Bleue (upper centre) where most of the Colloquia will be held. IUGS will have a permanent office on this level during the Congress - in Room 304.



Level 5 has some of the larger conference halls, including the Salle Havane (lower left) where both the Congress Council and the IUGS Council will meet (on July 7, and July 7, 10 and 15 respectively). Many of the scientific Sections will meet on this level as well.

Third Circular: Latest on Scientific Program . . .

The Third Circular on the Congress containing the latest information on the scientific program, publication plans and scientific excursions will be available in April (and will be distributed at about the same time as this issue of EPISODES).

It will serve as a supplement to the Second Circular, which participants are asked to keep and bring to the Congress. Both Circulars are available from the Secretariat of the 26th IGC at the following address: **Secrétariat du 26e CGI,
Maison de la Géologie,
77-79, rue Claude-Bernard,
F-75005 Paris, France**
Telephone: (1) 707-9196,
Telex: VOSEIL 202 353 (attention: 26th IGC)

Excursions

The international organizing committee for excursions has now finalized the list of pre- and post-Congress field trips to be offered this summer, as follows (* denotes excursions fully booked as of April 1):
001 C; **002** A*; **003** A; **010** A; **011** A; **023** A; **027** C*; **031** A; **032** C*; **034** A; **041** A; **042** A; **043** C; **063** C*; **066** C; **078** A*; **078** C*; **079** C; **080** C; **081** C*; **082** A*; **085** A; **087** A; **091** C; **093** A; **095** C*; **096** A*; **103** A; **105** A; **117** C; **122** A*; **126** A; **131** C; **133** C; **138** A; **140** C; **141** C; **149** C; **151** C; **160** C; **164** C; **204** C; **205** A; **206** A*; **208** C; and **210** C*.

Excursions have been organized by 16 European countries. In addition to these, several one- or two-day excursions will take place during the Congress itself - chiefly visits to nearby industrial and scientific institutions and to study the geology of the Paris Basin.

For further details, please consult the Second and Third Congress Circulars.

Exhibits

"GEOEXPO 80" - the scientific and technical exhibition of the Congress - promises to be a memorable one, with a total of 140 exhibitors occuping some 230 booths.

The accent is on Europe, where contemporary research and mining applications are among some of the more advanced in the world. Exhibitors include research institutes, governmental geological surveys, companies, manufacturers of field and laboratory equipment, publishers and scientific societies.

The exhibition will run from July 7 through July 11 on Level 1 of the Palais des Congrès.

Festival of Scientific Films

Focussing on earth sciences, their applications and results, a series of short films will be shown every afternoon from July 8 through July 12 in the Palais des Congrès.

Films to be projected will include both professionally produced and amateur ones, with either English or French soundtracks or sub-titles in one of these languages.

Bookshop

The 26th IGC has stimulated an impressive amount of geoscientific publication activity all over Europe, and Congress organizers have made every effort to synthesize the different aspects of European geology in several series of publications (see "26th IGC - Update...Publications" in EPISODES, Vol. 1979, No.4, p. 30).

To facilitate the purchase of these, and numerous other professional and general-interest publications, the Congress will operate a Bookshop on Level 1 of the Palais des Congrès - in the registration area. The Colloquia papers, a number of new publications on metallogeny, as well as the excursion guide-books will also be available at the Bookshop.

Social Program and one for "Junior" too!

A concert in the Cathedral of Notre-Dame - the masterpiece of mediaeval Gothic art, a reception in the Grand-Palais, (originally erected for the Great Exhibition of 1900), a panoramic tour of Paris and its many wonders, outings into the delightful French countryside - to Chartres, the "Acropolis of France", and to Orléans, the city delivered from siege in the fifteenth century by Joan of Arc, now headquarters of the BRGM - these are just some of the many attractive options planned by the Organizing Committee for the socially-minded Congress participant and his/her accompanying member.

With July 14, France's "Bastille Day" and a national holiday coming right in the middle of the Congress, and with no scientific sessions planned for that day, some of the suggested social functions may prove to be very popular.

And as for participants' "juniors" (anyone between the age of 8 and 16 qualifies), a day-camp has been organized to run from July 8 to 12 inclusive, geared to make science exciting for the young mind; activities will include field geology, adventures into astronomy and even the launching of small rockets (all under the supervision of experts in each field).

IUGS Council: Session VI

IUGS Council will meet in three sessions during the 26th IGC - July 7 (9:00 a.m. to 12:00 p.m.), July 10 (6:30 p.m. to 8:30 p.m.), and July 15 (6:30 p.m. to 8:30 p.m.); all meetings will take place in the Salle Havane on the 5th Level of the Palais des Congrès.

The provisional agenda for the VI Ordinary Session of Council has been distributed to all member countries, 34 of which have indicated (as of April 1, 1980) that they will be sending delegates to Paris. It is anticipated that the extensive number of key issues requiring Council debate will make it necessary to schedule another meeting - tentatively set for July 11 (6:30 p.m. to 8:30 p.m.) - but this will be decided on during the July 10 meeting. The IUGS Treasurer and Secretary General are currently reviewing the status of payments for membership dues to determine which countries are eligible to vote during the Council Session.

Special IGCP Session

"Eight Years of IGCP" is the theme of a special session scheduled for Tuesday, July 15 from 2:00 to 6:00 p.m. in Conference Room 51 (5th Level) of the Palais des Congrès.

Distinguished scientists addressing the session will include **D.J. McLaren** (Chairman of the IGCP Board), **J.V. Watson** and **A.W. Bally** speaking on "Scientific Achievements", **J.A. Reinemund** on "Project Linkage and Distribution", **G.O. Kesse** on "Application to Human Needs" and **C. Karunakaran** on "Further Development of the Programme".

This session will provide a unique opportunity for those interested in the IGCP, its Projects and Working Groups to attend and take part in the discussions.

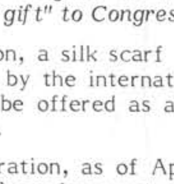
Registration Kits

Congress registration kits will include seven volumes of papers (in English and French) presented at the Colloquia, three volumes of abstracts (covering both the Sections and the Colloquia), four maps (geological maps of Europe and France, a map on mineral deposits in France and a hydrogeological map of France), vouchers for some of the social functions, including the Opening Ceremony and the Reception following it, a copy of the magazine Annales des Mines, a souvenir bronze medal commemorating the centenary of the IGC, and, of course, the Congress Program and badge which will admit participants to all plenary, Section and Colloquia sessions.

92 mm in diameter and weighing 400 g, a handsome bronze medal showing the surface morphology of the earth in relief has been designed to mark the centenary of the IGC - a "souvenir gift" to Congress participants at registration.

In addition, a silk scarf has been specially designed for the Congress by the internationally acclaimed house of Hermes and will be offered as a gift to participants' accompanying members.

Preregistration, as of April 1, 1980, was nearing the 4,000 mark. *(If you have not as yet sent in your registration form, please do so as soon as possible. To receive a form, send your name and address to:* ***Secrétariat du 26e CGI, Maison de la Géologie, 77-79, rue Claude-Bernard, F-75005 Paris, France.***



A Hermes scarf, beautifully designed in celebration of geology's many diverse subdisciplines, will be presented to all participants' accompanying members.

Meet Some of the Organizers:

An active Organizing Committee, efficiently and effectively orchestrated by the Secretary General, **Paul Sangnier**, has been hard at work for the past four years "ironing out" every detail of the 26th IGC.

Congress planning and organizing has been handled by several groups of people. The 26th IGC Secretariat has been responsible for the overall coordination of planning and day-to-day administration and execution of Congress plans. The Secretariat includes **Mr. J. Halfon** - Deputy Secretary General, **Mme. Brigitte Sangnier** - Executive Assistant to the Secretary General, **Mme. M.J. Leinhardt** - Abstracts Compiler, **Mr. R. Bourrouilh** - Treasurer; **Mme. L. Bourlard** - Secretary, and **Mr. J.F. Stuyck-Tallandier** - Consultant to the Secretary General.

As President of the 26th IGC, **Prof. J. Aubouin** (see page 51) has been ably assisted by his Vice Presidents, Messrs. **C. Allègre, J. Bodelle, J. Dercourt** and **C. Sallé.**

In addition, a series of committees have dealt with specific aspects vital to the success of the Congress: publications (headed by **L. Delbos** and **C. Lorenz**), excursions (**J.**

Dercourt, C. Cavelier and M. Degouy), finance (Mr. C. Beaumont), industrial liaison (P. Routhier and G. Troly), scientific program (G. Aubert and R. Blanchet), program for accompanying members (Mme. A.M. Godard), social program (Mr. P. Cliquet and C. Sallé), public relations and exhibition (Mr. J. Ricour), travel/accommodation (Mme. F. Dubois and Mlle. M. Verdoia of Voyage-Conseil, the official travel agency of the Congress).

A full list of members of all committees will appear in the Third Circular.

Some of the key organizers of the 26th IGC gather outside the Bureau de Recherches Géologiques et Minières (BRGM) in Orléans, France; left to right: Mr. Paul Sangnier, Mme. Brigitte Sangnier, Mme. M.J. Lienhardt, Messrs. L. Delbos, M. Degouy and C. Cavalier.

50 Years Ago . . . .

Paul Charrin (now an oil and mining consultant in Houston, U.S.A.) has sent in a photograph of some of the participants in the XVth IGC, held in Pretoria, South Africa in July, 1929, with the following recollections:

"For most of us in Pretoria, it was our first contact with the old Gondwanaland and this may be one of the reasons why even after 50 years, the memories of the XVth Congress are still vivid.

This was the first Congress held in the Southern Hemisphere. The second one (in Sydney, 1976) would attract thousands of geologists, but in Pretoria there were only 298 in attendance. The fastest means of reaching South Africa then was by ship - 17 days from Southampton to Cape Town, and from there, two days and nights by train to Pretoria. I was lucky: coming from Katanga, it was just a three-day trip for me.

The atmosphere was friendly and conducive to meeting and exchanging ideas. The photograph below includes some well known faces and some who would later become well-known. Some have since passed away, including **Don Garcia Sineriz** (first row, in the middle) who represented Spain and officially opened the Congress."

XVth IGC, Pretoria, South Africa, 1929.

Survey of World's Geologists

At the initiative of **J. Bodelle** (Director of the French National Geological Survey in the BRGM and a Vice President of the 26th Congress), and in collaboration with national committees for geology across the world, a survey on the world-wide distribution of geologists has been completed, the results of which will be presented at the Congress under Section 20.

The survey contains data on the number of geologists around the world, the regional distribution of the geological community, correlations between this information and data on general population in countries, gross national products, and the like. A unique global venture, it should prove to be of interest to many Congress participants.

Possible Formation of EGA

European Geological Societies have been urged by the EGA Bridging Committee to have their Councils and representatives formally support a proposed European Geological Association (EGA) during a plenary session scheduled during the 26th IGC.

The Societies have met twice since 1975 (see MEGS II Conference Report in EPISODES, 1978, No. 2, p. 34), both meetings having been coordinated by the Bridging Committee (Convenor - **J.V. Hepworth** of the Geological Society of London). A constitution for the proposed EGA was drawn up and discussed in Amsterdam during MEGS II: its basic objective is to ensure that regular meetings focussing on European geology take place every two or three years on a continuing basis.

While the fourth "MEGS" meeting has been tentatively scheduled for Easter, 1985 in Edinburgh, Scotland - in celebration of the 150th anniversary of the Geological Society of Edinburgh and the anniversary of the Geological Survey, a venue for the third meeting (1981) has not as yet been found; possibilities are being explored by a Dutch committee led by **Dr. H.J.W.G. Schalke.**

Geological Society of France Marks 150th Anniversary

To celebrate its "150th Jubilee", the Geological Society of France is publishing a book on the status of French knowledge in the different branches of earth science - paleontology, stratigraphy, sedimentology, petrology, tectonics, geophysics, geochemistry and applied geology.

Alain Perrodon, President of the French National Committee on Geology, informs us that the Society will celebrate its 1830 founding in a ceremony just prior to the 26th IGC. The Society hopes to maintain its tradition of close cooperation with other associations so as to better advance the development of geoscience and its application.

International Tectonic Lexicon

An International Tectonic Lexicon bringing together a first selection of important tectonic terms, explaining their meaning and suggesting equivalents in the six official languages of IUGS - English, French, German, Italian, Russian, and Spanish, has been published on behalf of the former IGCP Project 100 - "International Tectonic Lexicon".

John Dennis informs us that Part I of the Lexicon ("Fundamental Tectonic Terms"), includes terms considered to be important in geological documentation, while Part II - "Terminology of Cleavage and Schistosity", is designed to be a prototype for similar compilations in other specialized areas. The Lexicon has been called a prodrome because it is a preliminary publication, completed with limited funds.

News In Brief . . .

Geological terms and, more particularly, tectonic terms have long suffered from disagreements as to their definition. Ideally, scientific terms are precisely defined, and carry a fixed, universally agreed connotation. If this were so in geology, it would be safe to say that a great many controversies need never have arisen. In reality, tectonic terminology suffers from semantic inconsistencies which hamper communication between geologists and other scientists, between geologists speaking different languages, and even between geologists speaking the same language.

The Lexicon became a project of CGMW's Subcommission for the Tectonic Map of the World at the 21st IGC in 1960. Responsibility for the project was assigned to CGMW itself at the 22nd IGC in 1964. Since then, a number of single-language terminologies have appeared both in published and in typescript format under the general sponsorship of the Commission.

At the 24th IGC (1972), **Frances Delany,** Secretary-General of CGMW, submitted a prototype international lexicon of 16 tectonic terms in French, compiled from existing single language terminologies and designed as a model for a planned larger multi-language compilation. The opportunity to implement this larger project arose with the establishment of the IGCP. In 1974, **J.G. Dennis** and **H. Murawski** submitted an implementation proposal to IGCP through CGMW, which led to the establishment of IGCP Project 100 (with Messrs. Dennis and Murawski as editors and Miss Delany as project leader).

The editors circulated a provisional manuscript to Project members **F. Dunning** (U.K.), **A. Caire** (France), **K.B. Jubitz** (G.D.R.), **R. Rey** (Spain), **M. Manzoni** (Italy), **H. Masson** (Switzerland), **V.E. Khain** and **V.P. Kolchanov** (U.S.S.R.). Copies were also sent to an Advisory Panel which included **J. Debelmas** and **X. Le Pichon** (France), **P.B. King** and **J. Rodgers** (U.S.A.), and **R. Trumpy** (Switzerland). Comments and suggestions were incorporated into the original manuscript, and an editorial committee (consisting of **J. Dennis,** Chairman, **H. Murawski, H. Masson,** and **R. Sacchi**) thoroughly evaluated and amended existing material for the Lexicon.
The Lexicon can be ordered from: *E. Schweizerbart'sche Verlagsbuchhandlung, Johannesstrasse 3A, D-7000 Stuttgart-1, F.R.G.*

GEOREF Data Base Will Go Back to 1785

The American Geological Institute (AGI) and the U.S. Geological Survey (USGS) will share the cost of adding 288 000 old bibliographic references to the GEOREF data base. The USGS has awarded AGI $92,000 to cover its share of the project. By September 30, 1981, with the addition of the old citations, GEOREF's North American coverage will extend back to 1785, the time of Thomas Jefferson.

GEOREF provides access to the world's geoscience literature through printed bibliographies, indexes and computer searching. The data base contains more than 550 000 earth science references covering world geology back to 1967 and North American geology back to 1961.

Online searching allows a geoscientist or librarian to examine the entire data base from a terminal by telephone; specific topical searches may be ordered from GEOREF.

The old references will be taken from the Bibliography and Index of North American Geology for the years 1785-1960, and from the Bibliography and Index of Geology Exclusive of North America, for 1933-1966. GEOREF's Bibliography and Index of Geology, published monthly with cumulations, succeeded these publications in 1969.

The Bibliography and Index of Geology contains approximately 50 000 new citations each year. References in the monthly issues are grouped in 29 fields of interest, such as engineering and environmental geology, solid earth geophysics, and sedimentary petrology. The annual subscription rate is $750.

New UN Secretariat for Science and Development

A new high-level advisory policy unit - the Centre for Science and Technology for Development - is being established to carry out the recommendations of the UN Conference on Science and Technology for Development (UNCSTD) held in Vienna in August, 1979 (see EPISODES, 1979, No. 3, p. 38).

Serving the new Intergovernmental Committee which is to coordinate the various UN programs applying science and technology to development, the unit will be headed by an Assistant Secretary General and will absorb some of the resources of the Office of Science and Technology (which will be abolished).

The Centre will report to the Director General for Development and International Economic Cooperation - **Mr. Kenneth Dadzie.** Establishment of a voluntary interim fund is planned to provide new resources for the implementation of projects and programs which will advance science and technology in developing countries. The target set for the fund (to be administered initially by the UNDP) is $250,000,000 for the period 1980-81. Contributions to the fund and staffing of the new Centre are currently under debate.

International Comet Mission Proposed

The European Space Agency (ESA) and the U.S. National Aeronautics and Space Administration (NASA) are jointly seeking proposals for participation in an exploratory comet mission, tentatively scheduled to be launched in 1985 (if authorized). It would include a rendezvous with a short period comet - Tempel 2, and a flyby of a second, more active one - Halley's Comet, for comparative measurements.

Proposals are sought in three categories:
(i) investigations involving scientific instruments, analysis and interpretation of data from the proferred scientific instrumentation other than rendezvous spacecraft imaging, altimetry and radio telemetry instruments;
(ii) investigations from individuals who use the NASA-provided rendezvous spacecraft facilities (specifically, the imaging, radar altimeter and radio telemetry subsystems);
(iii) interdisciplinary investigations to solve problems in cometary science and/or provide meaningful theoretical and analysis support to the mission.

To be selected, proposals must fall within the overall objectives of the mission:
- to determine the chemical nature and physical structure of the comet nuclei, and characterize the changes that occur as functions of time and orbital position;
- to characterize the chemical and physical nature of the coma of the comets as well as the processes that occur therein, and characterize the development of the coma as functions of time and orbital position;
- to determine the nature of the comet tails, the processes by which they are formed, and characterize the interaction of comets with the solar wind.

For further information on this proposed mission, write to: *Office for Space Sciences, NASA, Code SL-4, Washington, DC 20546, U.S.A.*

IUGS Executive Meets in Mexico

XXIst Executive Committee Meeting
February 6-9, 1980

An agenda chock-full of new initiatives as well as routine matters awaited Executive Committee evaluation early in February as members gathered in Mexico City (for the first time in IUGS history) to attend the XXIst Executive Committee Meeting.

Key results of the session include:

. agreement on plans for launching a new inter-union program tentatively referred to as "Dynamics, Composition and Evolution of the Lithosphere" during the 26th IGC. A Steering Committee for the successor program to the International Geodynamics Project, appointed by IUGG and IUGS in mid-1979, met at the IUGG General Assembly in Canberra in December, and will meet again early in July to prepare a final document outlining the program, and to propose Bureau members, as well as specific Working Groups. Current plans also call for the submission of a report describing project plans to the ICSU Priorities Committee in April, to IUGS Council in July, and to the ICSU Finance Committee in late July; ICSU's final ratification of the program is expected in September at the General Assembly;

. establishment of two new advisory groups: (i) a small Standing Committee on Comparative Planetology, with **Prof. W. von Engelhardt** as Convenor of its first meeting (during the 26th IGC), and with representation from IAP, IMA, IAGC, NASA and the former IUGS Commission on Meteorites; and (ii) an ad hoc Advisory Committee on Sedimentology, also scheduled to meet at the 26th IGC, with **Prof. K. Hsu** acting as Convenor and with IAS, SEPM representation;

. creation of a new simplified IUGS publication series to encourage and facilitate publications emanating from IUGS-sponsored (or partially IUGS-sponsored) work to be credited to IUGS - by assignment of a Publication Number and, whenever possible, use of the IUGS logo, on the title page and/or the front cover. Terms of reference for this series have already been circulated to IUGS constituent bodies by the Secretary General and **Dr. M.G. Bassett** (Chairman, Advisory Board for Publication) who participated in the XXIst session; since then, three publications have been designated under the new system;

. agreement on the need for an IUGS Trust Fund and establishment of a task group (headed by **Professor P.F. Howard**, a Vice President) charged with defining Trust Fund objectives and operating procedures, as well as strategies for soliciting contributions to it. The concept of a Trust Fund was proposed a year ago by the Treasurer, **Dr. J.A. Reinemund**, a key member of the task group;

. discussion of a number of projects recommended for future IUGS support by participants in the Symposium "Metallogenesis in Latin America", sponsored by IUGS, the Mexican Consejo de Recursos Minerales, and others, just prior to the XXIst session (see "Conference Reports" in this issue). Since then, agreement has been reached that the following projects be given priority consideration: publication of Symposium papers, publication of a series on ore deposits of Latin America, preparation of a report on geochemical and geophysical prospecting/exploration in tropical regions, conducting of regional metallogenic studies of tin and associated minerals, conducting of a study of stratiform and stratabound sulfide deposits, and carrying out a study of ore deposits associated with mafic and ultramafic rocks. **Dr. Reinemund** heads a group determining the terms of reference and possible resources for these projects;

. acceptance of the final report of the Scientific Review Committee, prepared by Committee Chairman **Dr. J.M. Harrison.** Its recommendations will be discussed at the VI Ordinary Session of Council in July, which Dr. Harrison will attend;

. further debate of the proposed revised constitution, which led to several minor suggested amendments. It was agreed that Council debate only those articles which had been formally questioned by IUGS constituent bodies and member countries;

. a re-examination of the role of IFSEG in relation to its constituent societies - SEG, SGA and IAGOD - in the presence of representatives of all four bodies. The Executive encouraged continued cooperation amongst these societies, and agreed to approve applications for direct affiliation between them and IUGS; since then, all three societies have formally requested such affiliation;

Left to right: Prof. Ulrich Petersen, President of IFSEG, talks to IUGS Vice Presidents Prof. I.E. Altinli (Turkey) and Prof. Peter F. Howard (Australia) at the XXIst Executive Committee Meeting in Mexico City.

. appointment of a task group to examine the future of EPISODES and report on the various alternatives before the next Executive meeting in July. This followed the Committee's expressed concern that the current successful formula for producing EPISODES might be jeopardized in the imminent changeover of the IUGS Secretariat;

. approval of the plans for the 26th IGC as detailed by the Secretary General, **Mr. Paul Sangnier.**

The Committee reviewed the successful results of the two-stage contract between IUGS (COGEODATA) and CCOP (see EPISODES, 1979, No. 4, p. 28), commending **Dr. R. Sinding-Larsen** and **Dr. A.L. Clark** for establishing a model for augmenting IUGS resources which might be followed by other IUGS bodies. Members furthermore endorsed the Treasurer's assessment of the need for augmentation of IUGS income - through other international contracts, by increasing the units of contribution to IUGS (members' dues), improving the marketing and sales of IUGS publications, and establishing a Trust Fund.

Pending ratification by Council, the Carpathian-Balkan Geological Association, the Geological Society of Africa and the International Commission for Palynology were granted affiliate status, while Guyana was welcomed as a new member country. Since the XXIst session, the application of

Dr. Grantley Wainwright Walrond, Deputy Commissioner of the Guyana Geology and Mines Commission, meets Dr. Eckardt von Braun, Secretary of IGCP. Guyana has just been welcomed to the growing list of IUGS member countries.

Somalia for membership and that of the Association of Arab Geologists for affiliation have also been accepted through an Executive postal ballot.

(Detailed minutes of the XXIst Session are available, on request, from: *IUGS Secretariat, Room 177, 601 Booth Street, Ottawa, Canada K1A 0E8).*

IGCP Stresses Social Goals

An important social as well as scientific role is foreseen for the joint IUGS-UNESCO International Geological Correlation Programme during the next few years. This came out clearly in the opening remarks of **Dr. A. Kaddoura** (UNESCO's Assistant Director General for Science) at the eighth session of the IGCP Board meeting in Paris, February 25-29, and was echoed in the deliberations of the Board itself, chaired by **Dr. D.J. McLaren.**

The Board gave full support to the recommendations of the IGCP Scientific Committee which had met during the week immediately preceding the Board meeting. Specifically, the Scientific Committee, under the chairmanship of **Dr. A. Bally**, had suggested that IGCP Projects be grouped under two major categories - those dealing with geological events in space and time, and those pertaining to natural resources and the environment.

The recommendation came in the wake of the Scientific Committee's initiative to examine the fundamental objectives of IGCP, and in particular, the way in which the Programme could show leadership in more effective application of earth science to the problems facing humanity.

The Board strongly supported the Committee's proposal to launch a major regional program for the Precambrian of West Africa, and requested **Dr. G.O. Kesse**, one of the Board members, to head the study group which will examine how such a project might best be coordinated, implemented and financed.

The role of training as it relates to IGCP Projects was reviewed. There was general agreement that the development of workshops, seminars and courses at the early stages of certain Projects would be useful but would require increased funding from UNESCO.

The Board recognized that there was still a regional imbalance both in the location of Projects and that of Project Leaders; greater effort is required to promote IGCP through regional meetings that focus on the scientific results of Projects, and to use these in stimulating participation in current Projects as well as in proposing themes for new ones.

Conditional acceptance was given to one new Project entitled "Geological Events at the Eocene-Oligocene Boundary", proposed by **C. Pomerol. Dr. E. von Braun**, IGCP Secretary, noted that during 1980, the total number of Projects will be reduced to about 50 (from a high of 64 in the past) which should increase available funding for existing Projects. In reviewing the life-expectancy of the Programme, the Board concluded that in the future no Project should be accepted for more than a five-year duration.

In recognizing the changing goals of the Programme, the Board felt that it would be useful to prepare another comprehensive statement on IGCP's achievements by 1983, and that IGCP's participation in gatherings of potential global impact, such as ACAST (prior to UNCSTD) which **Drs. McLaren, Karunakaran** and **Oyawoye** attended on behalf of the Board, be encouraged.

In his closing remarks, Dr. McLaren paid tribute to **Dr. E.M. Fournier d'Albe,** the former representative of UNESCO in IGCP, who retired in September, 1979 as Director of UNESCO's Earth Sciences Division, and to the IGCP Secretariat in Paris (**Drs. E. von Braun, I. Rousko** and **Z. Huang**, as well as **Mme. C. Espinasse** and **Mme. S. Stoullig**).

The Scientific Committee was ably assisted this year by some energetic newcomers - **D. Ager** (U.K.), **G.P. Cooray** (Sri Lanka), **U.G. Cordani** (Brazil), **A.K. Mikkola** (Finland) and **M. Shannon** (Liberia).

At work during the eighth session of the IGCP Board in Paris, February, 1980 are, left to right, Dr. E. von Braun (IGCP Secretary), Dr. A. Kaddoura, Assistant Director General for Science, UNESCO, and Dr. D. J. McLaren (Chairman, IGCP Board).

UNESCO: New Educational Project in S and T

A new project aimed at adapting education in science and technology to a changing society and to the diversity of needs of UNESCO's Member States has been announced in the planned UNESCO program for 1979-1980.

Studies to be carried out under this project will pay attention to the dimensions of space and time in an effort to introduce more relevance and self-reliance in science education programs. To make certain that related "real-life" problems (food, shelter, health, hygiene, water and other natural resources, artificial materials, energy) and their social impacts are not neglected, specialists in these various areas will join efforts with science educators in reviewing educational needs and problems.

The emphasis will be on short studies-in-depth (focussing on concrete, well-defined situations) rather than long global studies, so as to ensure that all regions of the world and their diverse systems are covered and that attention is paid to problems that arise within the working life-time of the students.

Anyone wishing to contribute to this project (bibliographic information, analysis of needs in their part of the world, case studies, and the like) may write to: *Director of the Division of Science, Technical and Vocational Education, UNESCO, Place de Fontenoy, 75700 Paris, France.*

MEET OUR EXECUTIVE. . .

Jean Aubouin of France

Professor Jean Aubouin, President of the 26th IGC, during an official ceremony at the Academy of Paris.

A continuing series of short profiles on the IUGS Executive Committee members

In geology, there is a school of thought known as global tectonics. And in Europe, there is a man who gave this school of thought significant and worldwide impetus. A rare individual, this man has the capacity to channel his thinking into broad, purposeful and creative aims, but at the same time, to be a dreamer. Better still, he is a dreamer whose sense and wit are - to paraphrase Byron - with poesy allied.

In a recent interview, Jean Aubouin, President of the 26th International Geological Congress and Ex-officio member of the IUGS Executive, was asked how he would describe himself; with good-natured "tongue in cheek" he replied: "A jolly good fellow".

As fitting as the synopsis might be, it hardly does justice to his extraordinary versatility. His official *curriculum vitae*, for example, is a printed book of 67 pages, 25 of which are devoted to his publications alone, produced at a prodigiously balanced pace from 1951 through to the present (three publications are now in press, four more are in the final stages of preparation).

A quick scan of them reveals some internationally accepted classics: "Contribution à l'étude géologique de la Grèce septentrionale: les confins de l'Epire et de la Thessalie" (1959), which was the first reconstruction of the tectonics and palaeogeographic evolution of Greece; the excellent "Geosynclines" (1965) which first appeared in English, unfolding a logical thesis on the geotectonic development of mountain chains; and the "Précis de Géologie" in three volumes, which first appeared in 1967-68 and has since been reprinted and translated several times, including, very recently, into Spanish - thus providing a first comprehensive synthesis of the geology of Latin American countries.

Professor Aubouin's publications, as all of his many professional endeavours, bespeak a life-long fascination with tectonics. He confesses, "Tectonics has been my guiding star...I should really say 'geotectonics' - at the scale of whole mountains belts, for I've only had a 'polite' interest in microtectonics. When studying tectonics on a global scale, so much depends on the interpretation of ancient continental margins. In studying processes at active continental margins, one realizes that tectonics is both prospective and retrospective."

He divides his research work into several successive periods: the initial "Mediterranean" period was followed by an "American" period which encompassed analyses of a series of tectonic zones - the Andean cordillera, the Caribbean, western North America. The "Oceanic" period came more recently: "The most exciting moment for me personally," he recalls, "was my descent in 1978 in the submersible CYANA to a depth of 2800m into a canyon off the Côte Provençale." This was part of an IPOD investigation (Leg 67 of which he co-directed in May and June of 1979). Today, what he finds particularly fascinating and challenging is the relationship between stratigraphy and tectonics at continental margins: "It holds the key to unravelling tectonic evolution through time."

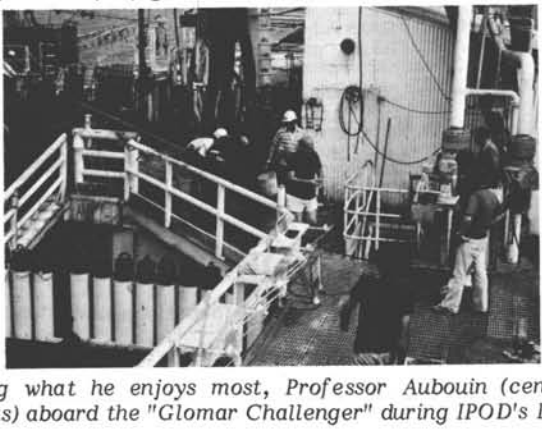
Professor Aubouin enjoys a reputation for inspiring and stimulating students. In fact, he regards his students as his greatest achievement: "I have always been attracted to the field of education. All levels of students - beginners and confirmed researchers - have appealed to me. A number of my students have now been professors for some time. Some of them are applying quantitative techniques in neotectonics, geodynamics and remote sensing. There are, you might say, three generations in our research family - the grandfather of which is still green...It's a family that some have described as a 'network' - or even a 'Mafia' - but don't believe a word of that!"

Professor at the Université Pierre et Marie Curie, head of the University's Department of Geotectonics and the Laboratory of Structural Geology (CNRS), Professor Aubouin serves on numerous national committees - at the CNRS, INAG, BRGM, CNEXO, CNES. He is currently President of the Commission for the Geological Map of the World. A master of oratory, he finds time to fit into his busy schedule of national and international commitments a continuous stream of speaking engagements all over the world (to say nothing of cheerfully agreeing to write an article on the geology of Europe for EPISODES!).

The forthcoming Congress is a special source of pride for him: "It has already led to useful collaboration among the Western European countries planning and organizing the field trips, collaboration which will hopefully endure beyond the Congress. There is such a need to bring people together every few years in a large international forum, to mix scientific disciplines, to focus on geology as a whole, to remove those sub-disciplinary 'blinkers' and, of course, to 'fly the flag!"

Married, with two children, Professor Aubouin is an accomplished cook; he loves cooking with a passion (shared by many of his countrymen), but he is quick to retract an impulsive confession made some time ago that he finds cooking more exciting than geology!

On the occasion of the 26th IGC and in behalf of IUGS and the many people who have had the privilege and the pleasure of working with him, EPISODES toasts Jean Aubouin - for his knowledge, for his heritage, for his diplomacy, for his delightful and infectious sense of humour, but most of all, for being such a "jolly good fellow" - which nobody can deny.



Doing what he enjoys most, Professor Aubouin (centre, in shorts) aboard the "Glomar Challenger" during IPOD's Leg 67.

FOR YOUR BOOKSHELVES . . .

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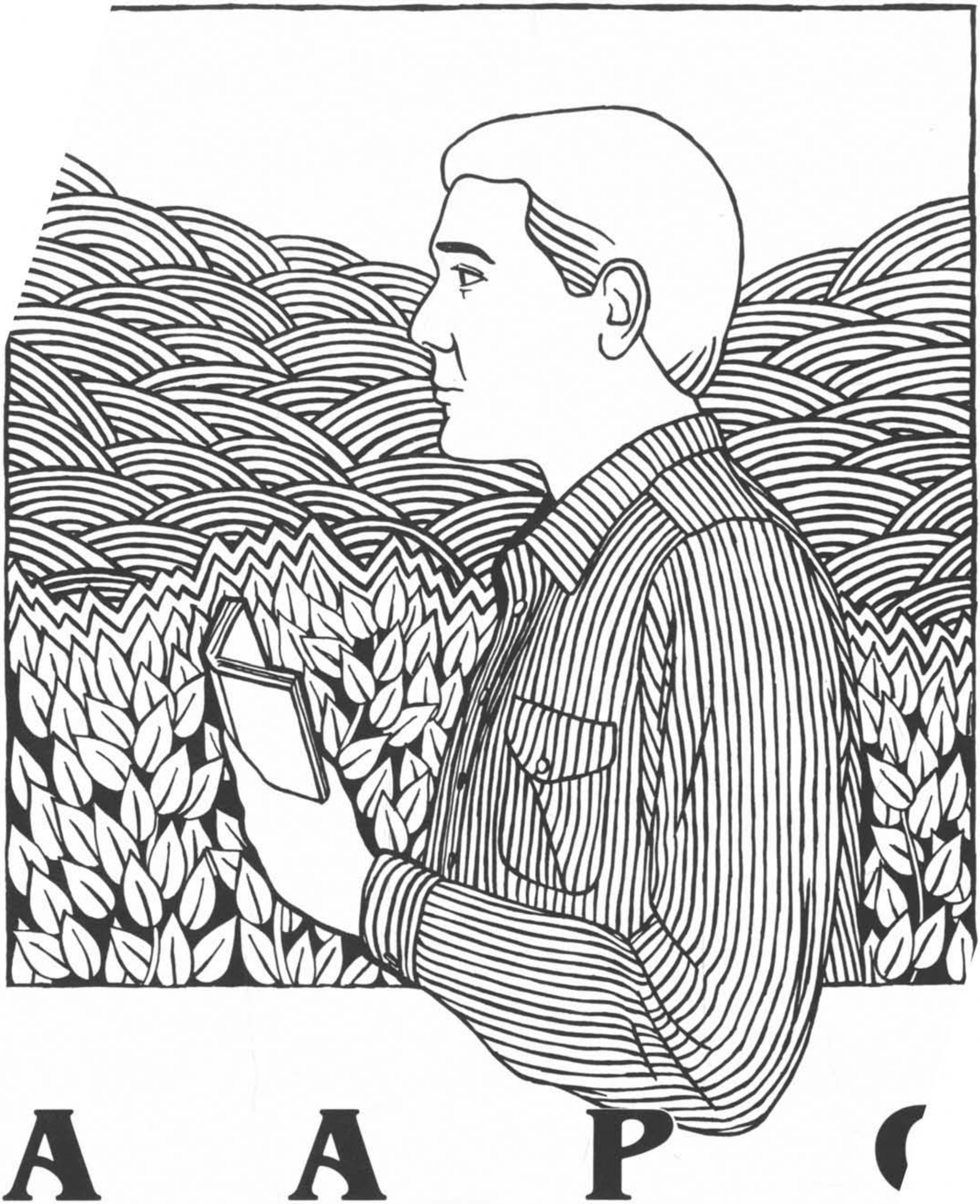
EL QAHIRA E7 1:1 500 000: International Geological Map of Europe, UNESCO and BGR, Hanover, (1980). Available from UNESCO Bookstores.

GEOLOGICAL MAP OF POLAND without Cainozoic and Cretaceous formations, 1:500 000. Wydawnictwa Geologiczne, Warszawa, (1978). Available from: Geological Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland (in Polish, Russian and English).

Jurowska, Z. and Kroczka, W. **MAP OF THE SEA-FLOOR DEPOSITS OF THE SOUTHERN BALTIC,** 1:500 000. Instytut Geologiczny, Warsaw, (1979), map with notes. Available from: Geological Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland.



COMING EVENTS

* Signifies events wholly or partially sponsored by IUGS, one of its Affiliated Associations or joint ventures - the International Geological Correlation Programme (IGCP) or the Inter-Union Commission on Geodynamics (ICG).

1980

May 12 - 16
GEOMECHANICS CONFERENCE, Wellington, New Zealand. (Secretary, Geomechanics Conference, Box 243, Wellington, New Zealand).

May 12 - 16
SCIENCE FOR A SUSTAINABLE SOCIETY FOR US BY 2000 A.D. WHY? HOW?, Adelaide, Australia. (ANZAAS Jubilee Congress, 141 Rundle Mall, Adelaide, S.A. 5000, Australia).

May 12 - 16
* **INTERNATIONAL ARCHAEAN SYMPOSIUM,** Perth, Australia. Sponsored by IGCP Project 92: Archaean Geochemistry and Geological Society of Australia with excursions before and after symposium. (J.A. Hallberg, Archaean Symposium, CSIRO, Division of Mineralogy, Private Bag, Wembly, Australia, 6014).

May 12 - 16
EARTHQUAKE PREDICTION, (Maurice Ewing Symposium), New Paltz, New York, U.S.A. (L.R. Sykes, Lamont-Doherty Geological Observatory, Columbia University, Palisades, N.Y. 10964, U.S.A.).

May 15 - 16
PROCESSES IN MAGMA CHAMBERS, Glasgow, U.K. (R.C.L. Wilson, Geological Society of London, Burlington House, London, W1V 0JU, U.K.).

May 16 - 17
ROCKY MOUNTAIN SECTION, GEOLOGICAL SOCIETY OF AMERICA, (Annual Meeting), Ogden, Utah, U.S.A. (R.W. Moyle, Dept. of Geology & Geography, Weber State College, Ogden, Utah, 84409, U.S.A.)

May 19 - 21
HALIFAX '80 - ANNUAL MEETINGS OF GEOLOGICAL ASSOCIATION OF CANADA/MINERALOGICAL ASSOCIATION OF CANADA, Halifax, Nova Scotia, Canada. (D.J.W. Piper, Secretary, Halifax '80, Department of Geology, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4H6).

May 19 - 21
* **THE APPALACHIAN OROGEN,** Halifax, Nova Scotia, Canada. Sponsored by IGCP Project 27. (P.E. Schenk, Dept. of Geology, Dalhousie University, Halifax, Nova Scotia).

May 19 - 24
* **CORRELATION OF CALEDONIAN STRATABOUND SULPHIDES,** Halifax, Nova Scotia, Canada. IGCP Symposium, Workshop and Field Trip. (D. F. Sangster, Geological Survey of Canada, 601 Booth Street, Ottawa, Canada, K1A 0E8. Tel: 613-995-4607).

May 22 - 27,
AMERICAN GEOPHYSICAL UNION, (Spring Meeting), Toronto, Canada. (AGU, 2000 Florida Avenue, N.W., Washington, D.C. 20009, U.S.A.)

May 26 - 30
OCEANOGRAPHY FROM SPACE, (Symposium), Venice, Italy. (J.F.R. Gower, Inst. of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada V8L 4B2. Tel: 604-656-8258. Telex: 049 7281).

May 26 - 30
4th INTERNATIONAL CONFERENCE ON ASBESTOS, Turin, Italy. (Conference Secretary, Vanni Badino, Istituto di Arte Mineraria Politecnico, Corso Duca degli Abruzzi 24, 10129 Torino, Italy).

May 27 - 30
ROCK MECHANICS, (Symposium), Rolla, Missouri, U.S.A. (D.A. Summers, Rock Mechanics and Explosives Research Center, University of Missouri, Rolla, Missouri, 65401, U.S.A.).

May 27 - 30
NATIONAL AND INTERNATIONAL MANAGEMENT OF MINERAL RESOURCES, London, U.K. Joint meeting of IMM and AIME. (The Secretary, Institution of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, England, U.K.).

May 28 - 31
WATER AND RELATED LAND RESOURCES SYSTEMS, (Symposium), Cleveland, Ohio, U.S.A. (AGU Meetings, 1909 K Street, N.W., Washington, D.C. 20006, U.S.A.).

May 28 - June 6
* **GEOSCIENCE MAPS FOR POTENTIAL OF NATURAL ENVIRONMENTS,** (Seminar), Lomé, Togo. Sponsored by CGMW and Unesco. (G. Lüttig, BGR, Stillweg 2, Postfach 51 01 53, D-3000 Hannover 51, F.R.G.).

June 2 - 4
APPLICATION OF ROCK MECHANICS TO CUT AND FILL MINING, (Conference), Lulea, Sweden. (O. Stephansson, University of Lulea, S-951 87 Lulea, Sweden).

June 3 - 6
42nd MEETING: EUROPEAN ASSOCIATION OF EXPLORATION GEOPHYSICISTS, Istanbul, Turkey. (A.W. Smit, Secretary-Treasurer, European Association of Exploration Geophysicists, 30 Carel Van Bylandtaan, The Hague, Netherlands).

June 3 - July 3
REMOTE SENSING: GEOLOGIC INTERPRETATION, (Course), Flagstaff, Arizona, U.S.A. Advanced training for non-U.S. scientists sponsored by USGS and Northern Arizona University. (Chief, Office of International Geology, U.S. Geological Survey, MS 917, National Center, Reston, VA 22092, U.S.A.)

June 8 - 11
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS AND SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS, (Annual Meetings), Denver, U.S.A. (J.P. Lockridge, 1176 Lincoln Street, Suite 712, Denver, 80203, U.S.A.).

June 11 - 13
APPLIED OIL-SANDS GEOSCIENCE, (Meeting), Edmonton, Canada. (M.B. Dusseault, Dept. of Civil Engineering, University of Alberta, Edmonton, Alta., Canada T6G 2G7).

June 18 - 30
TEPHRA STUDIES AS A TOOL IN QUATERNARY RESEARCH, Iceland. NATO Advanced Studies Institute and field trips. (R.S.J. Sparks, Dept. of Mineralogy and Petrology, Univ. of Cambridge, Cambridge, CB2 3EW, U.K.).

June 23 - 27
ROCK STORE 80, Stockholm, Sweden. Symposium on subsurface space for environmental protection, low cost storage and energy savings. (Secretary General, c/o Stockholm Convention Bureau, Strandvagen 7 c, S-114 56 Stockholm, Sweden. Tel: 08-630-445, Telex: S 115 56).

June 25 - 27
FORE-ARC SEDIMENTATION AND TECTONICS IN MODERN AND ANCIENT SUBDUCTION ZONES, London, U.K. (J.K. Leggett, Dept. of Geology, Imperial College, Prince Consort Road, London, SW7 2AZ, U.K.).

June 29 - July 6
* **FIFTH INTERNATIONAL PALYNOLOGICAL CONFERENCE,** Cambridge, England, U.K. Conference with field excursions. (Mrs. G.E. Drewry, Dept. of Geology, Sedgwick Museum, Downing Street, Cambridge CB2 3EQ, England, U.K.).

July 4 - 7
* **GENERAL MEETING OF THE INTERNATIONAL MINERALOGICAL ASSOCIATION,** (IMA), Orléans, France. Field excursions to Brittany and Massif Central, June 30 - July 3. Scientific and poster sessions July 4 - 7. Commissions and Working Group meetings, July 4. (Secrétariat de la 12ème Assemblée Générale de l'IMA, B.R.G.M., BP 6009, 45018 Orléans Cedex, France).

July 7 - 17
* **26th INTERNATIONAL GEOLOGICAL CONGRESS,** Paris, France. (Paul Sangnier, Secrétaire Général du 26ème C.G.I., Maison de la Géologie, 77-79 rue Claude-Bernard, 75005 Paris, France).

July 14 - 24
3rd INTERNATIONAL SYMPOSIUM ON WATER-ROCK INTERACTION, Edmonton, Alberta, Canada. Sponsored by IAGC and the Alberta Research Council. (B. Hitchon, Alberta Research Council, 11315 87th Avenue, Edmonton, Alberta, Canada T6G 2C2).

July 21 - 23
GEOLOGIC FUNDAMENTALS AND TECHNIQUES FOR GEOTHERMAL EXPLORATION AND DEVELOPMENT (Course), Klamath Falls, Oregon, U.S.A. (Beverly A. Hall or Sheila Roberts, Geothermal Resources Council, P.O. Box 98, Davis, CA 95616, U.S.A. Tel: 916-758-2360)

July 27 - August 1
COMPUTER GRAPHICS WEEK, '80, (Workshop), Harvard, U.S.A. (Laboratory for Computer Graphics, Harvard University, 48 Quincy Street, Cambridge, MA 02138, U.S.A.).

July 29 - August 10
SECOND EUROPEAN CONODONT SYMPOSIUM (ECOS II), Austria and Czechoslovakia. Symposium with pre- and post-symposium field trips co-sponsored by the Geological Survey of Austria and Geological Survey of Czechoslovakia. (ECOS II, Geological Survey of Austria, P.O. Box 154, Rasumofskygasse 23, A-1031 Vienna, Austria).

August 1 - 28
FORMATION OF PLANETARY SYSTEMS, (Course), Grasse, France. (Centre National d'Etudes Spatiales, Dépt. des Affaires Universitaires, 18 Ave. Edouard-Belin, 31055 Toulouse Cedex, France).

August 4 - 9
INTERNATIONAL SYMPOSIUM ON THE ACTIVITY OF OCEANIC VOLCANOES, Ponta Delgada, Azores. Co-sponsored by IAVCEI and Azores University with three post-meeting excursions. (Prof. F. Machado, Oceanic Volcanoes Symposium, Azores University, Horta, Azores).

August 11 - 16
MODERN SHELF AND ANCIENT CRATONIC SEDIMENTATION - THE ORTHOQUARTZITE-CARBONATE SUITE REVISITED, Wisconsin, U.S.A. First SEPM Research Conference. (C.W. Byers & R.H. Dott, Jr., Dept. of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706, U.S.A.)

August 15 - 28
9th CARIBBEAN GEOLOGICAL CONFERENCE, Santo Domingo, Dominican Republic. Conference with concurrent and post-conference field trips. (W.E. Snow, Coordinator, 9th Caribbean Geological Conference, Apartado 2719, Santo Domingo, Dominican Republic).

August 18 - 20
AUTOMATION IN MINING, MINERAL AND METAL PROCESSING, Montreal, Canada. (Secrétariat, IFAC/AMMMP, Centre de Développement Technologique, Ecole Polytechnique, C.P. 6079, Succ. 'A', Montréal, Québec, Canada H3C 3A7).

August 24 - 29
EGS BUDAPEST '80, Budapest, Hungary. Seventh Annual Meeting, European Geophysical Society. (EGS-ESC Budapest '80, Geophysical Dept., Eötvös University, H-1083 Budapest, Kun Béla tér 2, Hungary).

August 25 - 29
* **MAGNETIZATION OF PLIOCENE AND QUATERNARY SEDIMENTS,** (Workshop), Budapest, Hungary. Meeting of IGCP Project 128. (P. Marton, Geophysics Dept., Eötvös University, H-1083 Budapest, Kun Béla tér 2, Hungary).

August 29 - 31
NEOTECTONICS FIELD EXCURSION, Tokyo, Japan. Co-sponsored by INQUA National Group on Quaternary shorelines and IGCP National Group for Project 61: Sea Level. Will precede 24th Int. Geographical Congress. (Y. Ota, Dept. of Geography, Yokohama National University, Tokiwadai, Hodogaya-ku, Yokohama, 240 Japan).

September 1 - 5
INTERNATIONAL GEOGRAPHICAL CONGRESS, Tokyo, Japan. (E. Bird, University of Melbourne, Parkville, Victoria, Australia, 3052).

September 1 - 6
6th SYMPOSIUM ON LIVING AND FOSSIL DIATOMS, Budapest, Hungary. Meeting with one-day excursion. (Marta Hajos, Hungarian Geological Survey, H - 1442 Budapest, P.O.B. 106., Hungary).

September 2 - 6
METEORITICAL SOCIETY,(Annual Meeting), La Jolla, California, U.S.A. (K. Marti, B-017, Chemistry Dept., Univ. of California, La Jolla, CA 92093, U.S.A.).

September 6 - 10
STRATIGRAPHY OF WYOMING, (Symposium), Teton Village, Wyoming, U.S.A. (W.R. Merschat, Gulf Oil Corporation, P.O. Box 2619, Casper, Wyoming 82602, U.S.A.).

September 8 - 12
4th MEETING OF THE EUROPEAN CLAY GROUPS, (Conference with field excursions), Munich, F.R.G. (U. Schwertmann, Institut für Bodenkunde der TU München, 8050 Freising-Weihenstephan, F.R.G.).

September 8 - 12
ELEVENTH WORLD ENERGY CONFERENCE, Munich, Federal Republic of Germany. Technical sessions will focus on energy sources and their future availability. (Organizing Committee, 11th World Energy Conference, Lindenmannstrasse 13, 4000 Düsseldorf 1, Federal Republic of Germany).

September 8 - 13
WORLD CONFERENCE ON EARTHQUAKE ENGINEERING, Istanbul, Turkey. (A. Gurpinar, Secretary, 7 WCEE, Yuksel Caddesi 7/B, Ankara, Turkey).

September 8 - 16
HYDRAULIC RESEARCH AND RIVER BASIN DEVELOPMENT, Nairobi, Kenya. Seminar sponsored by the International Association for Hydraulic Research and UNESCO. (S. Bruk, Inst. for Water Resources, 'Jaroslav Cerni', Vele-Nigrinove 16, Belgrade, Yugoslavia).

September 8 - October 3
15th INTERNATIONAL REMOTE SENSING WORKSHOP, Sioux Falls, South Dakota, U.S.A. Course at EROS Data Center for non-U.S. scientists. (Chief, Office of International Geology, U.S. Geological Survey, MS 917, National Center, Reston, VA 22092, U.S.A.).

September 9 - 11
GEOTHERMAL ENERGY FOR THE 80's, Salt Lake City, U.S.A. Annual Meeting, Geothermal Resources Council and conference with pre- and post-meeting field trips. (Beverly A. Hall or Sheila Roberts, Geothermal Resources Council, P.O. Box 98, Davis, CA 95616, U.S.A. Tel: 916-758-2360)

September 17 - 19
EUROTUNNEL '80, Basel, Switzerland. Conference on Tunnelling in Europe. (Secretary, Institution of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, U.K.).

September 22 - 26
THIRD INTERNATIONAL CONGRESS ON THE HISTORY OF OCEANOGRAPHY, Woods Hole, Massachusetts, U.S.A. Celebration of 50th Anniversary of Woods Hole Oceanographic Institution. (J.H. Steele, Director, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, U.S.A.).

September 28 - October 1
ENERGY AUDIT OF THE 80's, (Conference), Calgary, Alberta, Canada. (G.D. Grant, Chevron Standard Ltd., 400 Fifth Avenue, SW, Calgary, Alberta, Canada T2P 0L7).

September 28 - October 4
SILICIC VOLCANISM, (GSA Penrose Conference), San Juan Mountains, Colorado, U.S.A. (P.W. Lipman, U.S. Geological Survey, Mail Stop 913, Federal Center, Denver, CO 80225, U.S.A.).

September 29 - October 2
ASSEMBLY ON: WILL WE USE THE OCEANS WISELY? THE NEXT 50 YEARS IN OCEANOGRAPHY, Woods Hole, Massachusetts, U.S.A. Part of celebration of 50th Anniversary of Woods Hole Oceanographic Institution. (J.H. Steele, Director, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, U.S.A.).

October 5 - 8
COMPLEX SULPHIDE ORES, Rome, Italy. Organized by the Institution of Mining and Metallurgy in association with the Laboratorio per il Trattamento dei Minerali, Consiglio Nazionale delle Richerche. (The Secretary, Institution of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, England, U.K.).

October 6 - November 7
REMOTE SENSING: LAND USE PLANNING AND ENVIRONMENTAL APPLICATIONS, (Course), Flagstaff, Arizona. Advanced training for non-U.S. scientists sponsored by USGS and Northern Arizona University. (Chief, Office of International Geology, U.S. Geological Survey, MS 917, National Center, Reston, Virginia 22092, U.S.A.).

October 8 - 11
SEVENTH INTERNATIONAL CODATA CONFERENCE, Kyoto, Japan. (Y. Mashiko, c/o Japan Society for CODATA, Dai-ichi Kanamori Building, 1-5-31 Yushima, Bunkyo-ku, Tokyo, 113 Japan).

October 9 - 11
* **METALLOGENY OF MAFIC AND ULTRAMAFIC COMPLEXES: THE EASTERN MEDITERRANEAN - WESTERN ASIA AREA AND ITS COMPARISON WITH SIMILAR METALLOGENIC ENVIRONMENTS IN THE WORLD**, Athens, Greece. Organized by the National Technical University of Athens and IGCP Project 169 (UNESCO-IUGS) and sponsored by IUGS with post-meeting field excursions to Greek ophiolite complexes with Cr-Ni and magnesite deposits. (S.S. Augustithis, National Technical University, Dept. of Mineralogy, Petrography, Geology, P.O. Box 1482, Athens, Greece).

October 13 - 17
SECOND INTERNATIONAL CONFERENCE OF SCIENTIFIC EDITORS, Amsterdam, Holland. (J.L.Heller, U.S. Geological Survey, MS 303, Box 25046, Federal Center, Denver, Colorado 80225, U.S.A.).

October 19 - 22
ASSOCIATION OF EARTH SCIENCE EDITORS, Halifax, Canada. (M. Latremouille, Bedford Institute of Oceanography, Box 1006, Dartmouth, N.S., Canada B2Y 4A2).

October 20 - 24
DIGITAL TECHNIQUES FOR GEOLOGICAL REMOTE SENSING APPLICATIONS, (Advanced course), Sioux Falls, U.S.A. (D.L. Lauer, Applications Branch, EROS Data Center, U.S. Geological Survey, Sioux Falls, South Dakota 57198, U.S.A.)

October 26 - 30
FUNDAMENTALS OF COMPUTER PROCESSING OF OFFSHORE MINERAL AND OTHER GEOLOGICAL DATA, (Seminar/Workshop), Bangkok, Thailand. Sponsored by Dept. of Mineral Resources, Asian Inst. of Technology and CCOP. (Pisoot Sudasna, Dept. of Mineral Resources, Ministry of Industry, Rama VI Road, Bangkok, Thailand).

November
SYMPOSIUM AMAZONICO, Puerto Ayacucho, Venezuela. Symposium organized by the Ministerio de Energia y Minas, Venezuela in cooperation with the Consejo Consultivo de Directores de Servicios Geologicos de Latinoamerica. (Symposium Amazonico, Ministerio de Energia y Minas, Direccion de Geologia, Torre Norte - Piso 19, Centro Simon Bolivar, Caracas, Venezuela).

November 5 - 7
GEOCHEMICAL FUNDAMENTALS AND TECHNIQUES FOR GEOTHERMAL EXPLORATION AND RESEVOIR EVALUATION, (Course), Reno, Nevada, U.S.A. (Beverly A. Hall or Sheila Roberts, Geothermal Resources Council, P.O. Box 98, Davis, CA 95616, U.S.A. Tel: 916-758-2360)

November 10 - 12
GEOCHEMISTRY OF ORGANIC MATTER IN ORE DEPOSITS, Warrenton, Virginia, U.S.A. (P.E. Hare, Geophysical Laboratory, 2801 Upton Street, NW, Washington, DC, 20008, U.S.A.).

November 11 - 13
11th ANNUAL UNDERWATER MINING INSTITUTE, Savannah, Georgia, U.S.A. (Barbara J. Arnold, Univ. of Wisconsin, Sea Grant Advisory Services, 1815 University Avenue, Madison, WI 53706, U.S.A. Tel: 608-262-2814).

November 16 - 20
GEOPHYSICS: A HALF CENTURY OF PROGRESS, Houston, U.S.A. Fiftieth Anniversary, Society of Exploration Geophysicists. (D.L. Yowell, SEG, Box 3098, Tulsa, OK 74101, U.S.A.).

November 17 - 20
GEOLOGICAL SOCIETY OF AMERICA, (Annual meeting), Atlanta, U.S.A. (GSA, 3300 Penrose Place, Boulder, CO 80301, U.S.A.).

November 18 - 21
SPACE GEODESY AND ITS APPLICATIONS, (Symposium), Cannes, France. (Centre National d'Etudes Spatiales, Département des Affaires Universitaires, 18 Avenue Edouard-Belin, 31055 Toulouse Cedex, France. Télex: 531 081).

1981

February 9 - March 6
REMOTE SENSING: DIGITAL IMAGE PROCESSING, (Course), Flagstaff, Arizona, U.S.A. Advanced training for non-U.S. scientists sponsored by USGS and Northern Arizona University. (Chief, Office of International Geology, U.S. Geological Survey, MS 917, National Center, Reston, VA 22092, U.S.A.).

March 29 - April 4
INTERNATIONAL CONFERENCE ON ARID SOILS, Jerusalem, Israel. Organized by Commissions V and VI of the International Society of Soil Science and the Israel Society of Soil Science. (D.H. Yaalon, Dept. of Geology, The Hebrew Univ. of Jerusalem, Jerusalem 91000, Israel. Tel: 02-584249).

March 30 - April 10
EARLY EVOLUTION OF THE EARTH AND PLANETS, (NATO Advanced Study Institute), Newcasatle upon Tyne, U.K. (J.M. Walmsley, School of Physics, The University, Newcastle upon Tyne, NE1 7RU, U.K.).

April 13 - 15
11th COLLOQUIUM OF AFRICAN GEOLOGY, Milton Keynes, U.K. (A.C. Ries, Dept. of Earth Sciences, The Open University, Milton Keynes, MK7 6AA, U.K.).

April 28 - 30
MULTIDISCIPLINARY STUDIES ON HUDSON/JAMES BAY, (Symposium), Guelph, Ontario, Canada. (I.P. Martini, Dept. of Land Resource Science, Ontario Agricultural College, Univ. of Guelph, Guelph, Ont., Canada, N1G 2W1).

May 11 - 13
GEOLOGICAL ASSOCIATION OF CANADA AND MINERALOGICAL ASSOCIATION OF CANADA, (Joint Annual Meetings), Calgary, Canada. (A.V. Morgan, Dept. of Earth Sciences, University of Waterloo, Waterloo, Ont., Canada N2L 3G1).

May 13 - 15
INDUSTRIAL MINERALS, (Forum), Albuquerque, New Mexico, U.S.A. (G.S. Austin, New Mexico Bureau of Mines & Mineral Resources, Campus Station, Socorro, N.M. 87801, U.S.A. Tel: 505-835-5125).

May 31 - June 3
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS AND SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS, (Annual Meeting), San Francisco, U.S.A. (Kathy Watson, AAPG, Box 979, Tulsa, OK 74101, U.S.A.)

May 31 - June 3
THE SHELF-SLOPE BOUNDARY - A CRITICAL INTERFACE ON CONTINENTAL MARGINS, (SEPM symposium), San Francisco, U.S.A. (D.J. Stanley, Division of Sedimentology, E 109, Museum of Natural History, Smithsonian Institution, Washington, D.C., 20560, U.S.A.).

June 24 - 26
ICAM 81 - INTERNATIONAL CONFERENCE ON APPLIED MINERALOGY IN THE MINERAL INDUSTRY, Johannesburg, South Africa. Pre- and post-conference field excursions. (L.F. Haughton, ICAM 81, Nat. Inst. for Metallurgy, Private Bag X3015, Randburg, 2125 South Africa).

June 28 - July 1
THIRD INTERNATIONAL SYMPOSIUM ON ARCTIC GEOLOGY, Calgary, Canada. (E.E. Pelzer, c/o Brunswick Resources Ltd., Suite 1401, 633 Sixth Avenue S.W., Calgary, Canada).

July 6 - 7
3rd INTERNATIONAL PLATINUM SYMPOSIUM, Pretoria, South Africa. (Symposium Secretariat S.217, CSIR, PO Box 395, Pretoria, 0001, Republic of South Africa).

July 7 - 11
SOUTHERN AFRICAN GEODYNAMICS PROJECT, Pretoria, South Africa. (Symposium Secretariat S.217, CSIR, PO Box 395, Pretoria, 0001, Republic of South Africa).

July 21 - 30
INTERNATIONAL ASSOCIATION OF SEISMOLOGY & PHYSICS OF THE EARTH'S INTERIOR, (General Assembly), London, Ontario, Canada. (A.E. Beck, Dept. of Geophysics, University of Western Ontario, London, Ont., Canada N6A 5B7).

August
* **THE SCANDINAVIAN AND GREENLAND CALEDONIDES REVIEWED**, Uppsala, Sweden. Symposium sponsored by IGCP Project 27 with excursions to Norway and Sweden. (D.G. Gee, SGU, Box 670, S-75128 Uppsala, Sweden).

August 7 - 16
4th INTERNATIONAL CONFERENCE ON BASEMENT TECTONICS, (Conference with field excursions), Oslo, Norway. Major theme: Origin, propagation and significance of basement fractures. (R.H. Gabrielsen, Dept. of Geology, University of Oslo, Box 1047, Blindern, Oslo 3, Norway).

August 9 - 14
* **SECOND INTERNATIONAL SYMPOSIUM OF THE CAMBRIAN SYSTEM**, Golden, Colorado, U.S.A. Sponsored by the Cambrian Subcommission of the IUGS Commission on Stratigraphy, and the U.S. Geological Survey. (The Cambrian Symposium, Paleontology and Stratigraphy Branch, U.S. Geological Survey, Box 25046, Mail Stop 919, Denver Federal Center, Denver, CO 80225, U.S.A.).

August 24 - 28
EARTH TIDES, (Symposium), New York, U.S.A. (J.T. Kuo, Aldridge Laboratory of Applied Geophysics, Henry Krumb School of Mines, Columbia University, New York, 10027, U.S.A.).

August 21 - 28
* **IGCP PROJECT ECOSTRATIGRAPHY**, Allekvia, Gotland, Sweden. Preceded by special collecting excursions and followed by the International Graptolite Conference - see below. (A.J. Boucot, Dept. of Geology, Oregon State University, Corvallis, Oregon 97331, U.S.A.).

September 1 - 6
* **SECOND INTERNATIONAL CONFERENCE, GRAPTOLITE WORKING GROUP OF THE INTERNATIONAL PALAEONTOLOGICAL ASSOCIATION**, (Conference and field excursions), Cambridge, U.K. (P.R. Crowther, Dept. of Geology, University of Cambridge, Sedgewick Museum, Downing Street, Cambridge CB2 3EQ, U.K.).

September 7 - 12
7th INTERNATIONAL CLAY CONFERENCE, Bologna and Pavia, Italy. Conference with pre- and post-meeting field trips. (F. Veniale Istituto di Mineralogia e Petrografia, Universita di Pavia, Via Bassi 4, 27100 Pavia, Italy).

September 21 - 25
MODERN AND ANCIENT FLUVIAL SYSTEMS: SEDIMENTOLOGY AND PROCESS, University of Keele, U.K. (T. Elliot, Singleton Park, Swansea, SA2 8PP, Wales, U.K.).

October 4 - 7
ASSOCIATION OF EARTH SCIENCE EDITORS, (Annual Meeting), Denver, U.S.A. (J. Heller, U.S. Geological Survey, Box 25046, Stop 303, Denver Federal Center, Denver, Colorado, 80225, U.S.A.).

October 5 - 8
GEOTHERMAL RESOURCES COUNCIL, (Annual Meeting), Houston, U.S.A.(Beverly A. Hall or Sheila Roberts, Geothermal Resources Council, P.O. Box 98, Davis, CA 95616, U.S.A. Tel: 916-758-2360)

October 7 - 9
ASSOCIATION OF SOUTHEAST ASIAN NATIONS COUNCIL ON PETROLEUM, (Meeting), Manila, Philippines. (ASCOPE '81 Organizing Secretariat, Philippine National Oil Co., 7901 Makati Ave., Makati, Metro Manila, Philippines. Telex: 63667 PNOC PM).

November 2 - 5
GEOLOGICAL SOCIETY OF AMERICA, (Annual meeting), Cincinnati, U.S.A. (GSA, 3300 Penrose Place Boulder, Colo. 80301, U.S.A.).

1982

May 12 - 14
9th INTERNATIONAL GEOCHEMICAL EXPLORATION SYMPOSIUM, Saskatoon, Canada. (L.A. Clark, Saskatchewan Mining Development Corp., 122 3rd Ave. North, Saskatoon, Sask., Canada S7K 2H6).

May 20 24
GEOLOGICAL ASSOCIATION OF CANADA AND MINERALOGICAL ASSOCIATION OF CANADA, (Annual Meeting), Winnipeg, Manitoba. (A.V. Morgan, Dept. of Earth Sciences, University of Waterloo, Waterloo, Ont., Canada N2L 3G1).

June 26 - July 1
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS AND SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS, (Annual Meeting), Calgary, Alberta. (Kathy Watson, AAPG, Box 979, Tulsa, Oklahoma, 74101, U.S.A.)

August 20 - 23
* **IV INTERNATIONAL SYMPOSIUM ON THE ORDOVICIAN SYSTEM**, Oslo, Norway. One pre-meeting excursion in Norway and three post-meeting excursions in Sweden. (D.L. Bruton, Paleontologisk Museum, Sars gate 1, Oslo 5, Norway).

August 22 - 28
CIRCUM-PACIFIC ENERGY AND MINERAL RESOURCES CONFERENCE, Honolulu, Hawaii, U.S.A. (M.T. Halbouty, 5100 Westheimer Road, Houston, Texas 77056, U.S.A.).

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