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ENCYCLOPEDIA
of
STRUCTURAL GEOLOGY AND PLATE TECTONICS

EDITED BY

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PREFACE

This encyclopedia was originally to be an encyclopedia of structural geology. As originally conceived, the encyclopedia would cover such classical concepts in structural geology as the description of folds, faults, joints, and so forth. However, when I took over as editor after Rhodes W. Fairbridge in 1984, I decided to also include plate tectonics in the encyclopedia. In part, this was necessitated by the revolution in geological thinking that followed the acceptance of the ideas of continental drift, seafloor spreading, and plate tectonics. Although Alfred Wegener originally published his ideas on continental drift in 1915, widespread acceptance of continental drift did not come until oceanographers demonstrated convincing evidence of seafloor spreading in the mid-1960s. In the late 1960s the idea of plate tectonics was proposed by W. Jason Morgan. He viewed the Earth's surface as being divided up into a number of relatively rigid plates that are moving relative to each other. Deformation of these plates, including folding, faulting, and mountain building is principally confined to the margins of these plates. Earthquakes, which are the result of movements along faults, are also principally confined to those margins.

The *AGI Glossary* contains short definitions of most, if not all, of the terms discussed in this encyclopedia, but one of the principal reasons for preparing an encyclopedia such as this one is to provide a much more extensive discussion of geologic terms than can be given in the *AGI Glossary.*

How To Use This Encyclopedia

The entries in this encyclopedia, which are in alphabetical order, vary from short to long depending in part on the relative importance of the subject. The length of the entries also depends on the number of subtopics discussed. For example, the article on Folds and Folding includes discussions of many topics such as anticlines, synclines, axial surface, and so forth. Alphabetically listed cross-references and the index provide the location of specific entries discussed under such general topics as Folds and Folding. Cross-references are also given at the end of entries when appropriate and these will provide additional readings on the subject covered in that particular entry. Additional references are given in the text of each entry to subjects discussed in that entry using (see name of article). References at the end of each entry will provide still additional sources of information on that entry.

The metric system is used frequently throughout the encyclopedia, and the conversion of metric units to English of length is given below:

Metric to English Units—Equivalents of Length

1 micron (μ) = 0.001 millimeter (mm) = 0.00004 inch (in)
1 mm = 0.1 centimeter (cm) = 0.03937 in
1000 mm = 100 cm = 1 meter (m) = 39.37 in = 3.2808 foot (ft)
1 m = 0.001 kilometer (km) = 1.0936 yard (yd)
1000 m = 1 km = 0.62137 mile (mi)
1 in = 2.54 cm
12 in = 1 ft = 0.3048 m
1 cm = 0.39370 in = 0.032808 ft
1 km = 10^5 cm = 0.62137 mile
1 fathom = 6 ft = 1.8288 m
1 nautical mile = 1.85325 km
1 in = 2.54001 cm
1 ft = 30.480 cm
1 statute mile = 1.60935 km = 5280 ft

Further Comments

The reader of this encyclopedia may notice that there are some disagreements in the interpretation of data from one entry to the next and sometimes these interpretations differed from those of the editor. I made the decision as editor *not* to try to make all entries consistent with each other (or with my views) but rather to let each author express his own viewpoint. In this way, the reader is exposed to differing views in much the same way that the reader is exposed to differing views in the geological literature. An effort was made, however, to at least indicate (and often reference) alternate interpretations where there is a major difference of interpretation among several authors published in the geological literature. Because much of geology involves reconstructing events which have occurred in the distant past, it is quite understandable that there are often strong differences of opinion on interpretations of data, and the encyclopedia reflects such differences.

Acknowledgments

I found much of the work on the encyclopedia was already completed when Rhodes W. Fair-

bridge asked me to take over, which made my task very much easier. I would like to extend special thanks to him for his continued assistance throughout the editing process. Thanks are also due to the many students who assisted me with the volume of paperwork, editing, and coordinating procedures, especially Sandy Gold and Sue Orrell who worked many long hours even after funds had run out. Thanks are also given to the exceedingly patient authors of the entries in the encyclopedia during the many years that the editing has taken. Support was also given by Charles Hutchison, publisher, Bernice Pettinato, managing editor, and Mary Dorian, production editor. My heartfelt thanks to each and every person listed above.

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The

ENCYCLOPEDIA

of

STRUCTURAL GEOLOGY AND PLATE TECTONICS

A

ABYSSAL PLAINS—See GEODYNAMICS.

ACCELERATING (TERTIARY) CREEP—See RHEOLOGY OF ROCKS.

ACCORDIAN FOLD—See FOLDS AND FOLDING.

ACCRETION STEPS—See SLICKENSIDES AND SLIKENLINES.

ACTIVE FOLDING—See FOLDS AND FOLDING.

ACTIVE SUBDUCTION—See UNDATION THEORY.

ALLOCHTHON

The term *allochthon* is derived from the Greek *allos* 'other' and *chthonous* 'of the earth.' Allochthonous objects have been displaced from their original site of origin, in contrast to *autochthonous* (*auto*, 'self') objects that remain indigenous or in situ. In geology, the term *allochthonous* has been used to characterize plant material transported from site of growth to site of deposition into coal seams (*allochthony*), for masses of redeposited sediments from distant sources, for constituents of derived magmas (cf. *allogenic components*), for transported and redeposited fossils (cf. remanié faunas), for impact crater ejecta, and for subterranean streams in karst regions.

In structural geology, an allochthon is a large allochthonous body of mappable, coherent rock such as the Taconic Allochthon of eastern New York (see Zen, 1967; Bird and Dewey, 1970) or smaller masses of chaotic, slumped rock and sediment, called *olistostromes*, such as those of the central and northern Apennines of Italy (see Elter and Trevisan, 1973). The term *allochthon*, first used by C. F. Naumann (1858), has had widespread usage in describing regions in orogenic belts where compression during orogenic evolution has emplaced masses of rock and sediment from distant root zones by overthrusting, or by gravity sliding (see *Gravity Slide Tectonics*) from uplifted terrains.

There are neither formally established conventions for the use of the term *allochthon* nor for criteria of dimensions for allochthons. For example, the Taconic Allochthon is approximately 250 km long and 50 km wide, whereas Apennine olistostromes range from several meters to many kilometers in lateral dimensions. Allochthons are characterized by discordant structural boundaries such as thrust faults and/or associated mélanges of sediment and rock, contrasting facies and rock types, and older or synchronous ages with respect to the underlying autochthon. The age of emplacement of the allochthon may be coeval with or younger than the youngest subjacent rocks or sediments of the autochthon. Some allochthons, such as portions of the Taconic Allochthon and the olistostromes of the Apennines, were emplaced as submarine slumps and gravity slides synchronously with deposition of autochthonous sediments on the autochthon. Allochthons may be stacked in a structural sequence (e.g., Zen, 1967). This stacking results in complex age relations involving various age differences of the allochthonous rocks and the autochthon and various times of emplacement of the successive allochthons, and it may involve differences in distance of transport of the various individual allochthons or allochthons comprised of sets of preexisting thrust sheets.

The terms *nappe* and *decke* (cover) have been used extensively for the huge allochthons that are recumbent folds and thrust sheets in the Alpine chain of Europe (see Trumpy, 1960). The term *klippe* is commonly used for an erosional outlier of a nappe or decke although, sensu stricto, a klippe may be simply an isolated erosional remnant of an autochthonous rock mass (see *Klippe*).

Sediments may be deposited on a moving submarine allochthon during emplacement. This leads to a complex time/space relation in which the superjacent sediments have varying degrees of allochthony and are said to be *epikinallochthonous* (*epi* 'upon,' *kine* 'moving'; Bird, 1969), to indicate that their transport was a consequence of having been deposited through an interval of time and space on a moving substrate. The delineation of epikinallochthons is derived from the analysis of deformational and sedimentary features and relationships that evolve diachronously with the evolution of the allochthon. Epikinallochthonous frameworks are difficult to decipher because they are syntectonic and may become severely distorted or even destroyed during their evolution. Later stages of epikinallochthonous sedimentation become parautochthonous or entirely autochthonous if such sedimentation continues after cessation of movement of the underlying allochthon. Conversely, during emplacement of allochthons, portions of the autochthon may become mobilized by the movement of the overriding allochthon, either in response to the forces imposed by the movement of the allochthon itself or as an effect of the forces driving the allochthon. Such tracts are also said to be parautochthonous. (The term *parallochthonous* should be avoided.)

Although it has long been recognized that allochthons of orogenic belts are a consequence of orogenic evolution, the mechanisms of formation and emplacement have remained a matter of complex debate among structural geologists. The sites of origin of large allochthons have been particularly difficult to locate in some orogenic belts such as the Appalachians and the Alps. With the advent of plate tectonics, it has been accepted that orogenic evolution is a consequence of lithosphere plate evolution. Specifically, Dewey and Bird (1970) argued that major allochthonous tracts have been emplaced in paratectonic zones and from orthotectonic zones driven by lithosphere plate subduction and that sources and root zones of the allochthons may be severely altered or even destroyed during lithosphere plate subduction.

Particularly important to this model are allochthons comprised of ophiolites, which are sequences of ultramafic, gabbroic, and basaltic rocks that originate as oceanic lithosphere and are derived by obduction (Coleman, 1971) from regions of subduction. Obduction of ophiolites is controlled by the geometry and diachronous evolution of consuming plate margins, or subduction zones. Such evolution can become extremely complex because of changes in poles of rotation of the involved lithosphere plates, diachronous evolution of triple junctions, and collisions involving island arcs and continental margins that result from lithosphere plate consumption. Good examples of ophiolite allochthons are in the Bay of Islands Complex, Newfoundland, and the Semail Complex of the Oman (see Dewey, 1976). Because of buoyancy constraints, cratonic rocks (continental crust) are not appreciably subducted. Given appropriate plate margin geometry, continental margins are converted to Andean-type orogenic belts and have continentward-directed paratectonic zones onto which allochthonous masses of sediment and oceanic lithosphere are driven from the regions of subduction, or orthotectonic zones, during cordilleran evolution. Extensive allochthons are also emplaced during continent-continent collisions such as that which occurred in the Himalayan Orogen during convergence of the Tibetan and Indian continents (Dewey and Bird, 1970).

Fig. 1 is a schematic illustration of the use of the various terms describing allochthons. The criteria of allochthony are derived from compositional and deformational aspects of the recognized allochthonous mass, whereas autochthons are defined with respect to unconformities because the unconformities can be linked with episodes or stages of tectonic evolution of the paratectonic zone. Usually, the autochthon, with respect to the first emplaced allochthon of a stacked set, is defined in terms of the closest underlying major unconformity that can be associated with the emplacement of the allochthon. This relation is shown in Fig. 1, where allochthon 1, a gravity slide or perhaps a recumbent fold, overlies a substrate containing an unconformity. This unconformity may be attributed to events in the orthotectonic zone that led to the emplacement of allochthon 1. However, rocks underlying the unconformity may also be unconformable on cratonic rocks and can be described as an older autochthon, or *palautochthon*, because the lowest unconformity predates the orthotectonic activity.

Submarine gravity slides may originate from subaerial terrains and, with movement into the autochthon, usually a flysch basin, develop an overlying unconformity. This unconformity may involve an epikinallochthon and be involved in the transport of the allochthon from source to submarine environment. Also, much of the upper surface of the allochthon may remain subaerial during movement and become unconformably overlain by sediments of the autochthon following emplacement. Such an unconformity can be used to define the base of a new autochthonous assemblage, neoautochthon 1, if the assemblage has been overridden by a new allochthon, illustrated by allochthon 2 of Fig. 1. Further orthotectonic activity, detaching deeper and more distant masses from the orthotectonic zone, may emplace an already assembled set of thrust sheets such as those illustrated by allochthon 3.

Cessation of activity in the paratectonic zone, either by cessation of orthotectonic activity or by displacement of the site of orthotectonic activity to more distant regions, may lead to changes in volumes and types of sediments deposited in the evolving autochthon and, perhaps, unconformable overlap of these sediments onto the para-

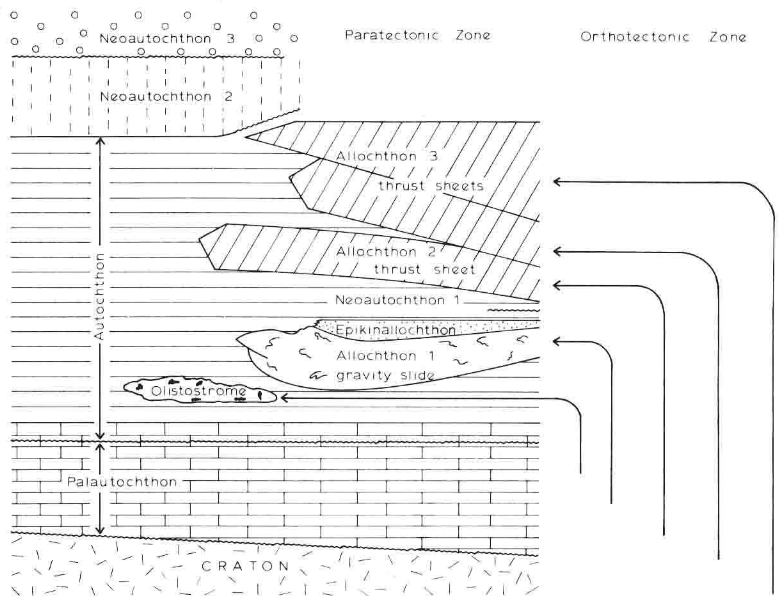

FIGURE 1. Schematic illustration of autochthonous-allochthonous relationships of tectonic structures.

tectonic region. Such new assemblages would constitute another new autochthon, neoautochthon 2, and contain a sedimentary record reflecting changes in the style and the extent of the tectonic activity. Such assemblages are important to recognize because erosion in the evolved paratectonic zone may destroy evolved structures; the neoautochthon may be the only record left of late-stage structures and/or tectonic activity in the paratectonic zone. Another superimposed episode of tectonic activity may produce another, different assemblage of sediment over the second neoautochthon. Such an assemblage, neoautochthon 3 in Fig. 1, might be related to the paratectonic zone only by sediment provenance because of complete erosion of the source regions of the fully evolved paratectonic-orthotectonic region.

JOHN M. BIRD

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ANDEAN-TYPE GEOSYNCLINE—See GEOSYNCLINES AND GEOCLINES.

ANTICLINAL BEND—See MONOCLINE.

APPALACHIAN OROGENIC BELT

Subdivisions of the Belt

The Appalachian Orogenic Belt is the belt of Paleozoic deformation along the southeast side of the North American continent that borders the central continental platform on that side. Its major exposed portion is the Appalachian Mountains (Fig. 1), which reach from central Alabama through the eastern United States and Canada to the Gulf of Saint Lawrence and which can be considered to include Newfoundland as well, but additional portions of the belt are concealed beneath the Atlantic Coastal Plain and the continental shelf from southern Georgia northeast as far as the Grand Banks. The belt of Paleozoic deformation can also be traced along a sinuous course beneath the Gulf Coastal Plain from Alabama to southwestern Texas and adjacent Mexico; marginal parts of the belt are exposed in the Ouachita Mountains of Arkansas and Oklahoma and the Marathon region of west Texas and in a few smaller areas in Texas and Mexico (Fig. 2).

The Appalachians were studied very early in the history of U.S. geology. Many classical ideas have been derived from them—e.g., strike regularity and asymmetry as characteristic of folding and thrust faulting in an orogenic belt (Rogers and Rogers, 1843), the geosyncline (Hall, 1883; Dana, 1873), anticlinal and carbon-ratio controls on oil accumulation (White, 1885; White, 1915), and the relation of low-angle décollement thrusting to folding (Rich, 1934).

With some important exceptions, structural features of all kinds exhibit a remarkable parallelism of strike along the Appalachian Belt; they trace out a sinuous path composed of smoothly arcuate salients, convex toward the center of the continent, and separated by more angular recesses, of which several are partly or wholly concealed by water or postorogenic sediments. From northeast to southwest, the larger curves are as follows:

Newfoundland Salient,
Gulf of Saint Lawrence Recess,
Quebec or northern Appalachian Salient (itself gently dimpled close to Quebec City),
New York Recess
Pennsylvania or central Appalachian Salient

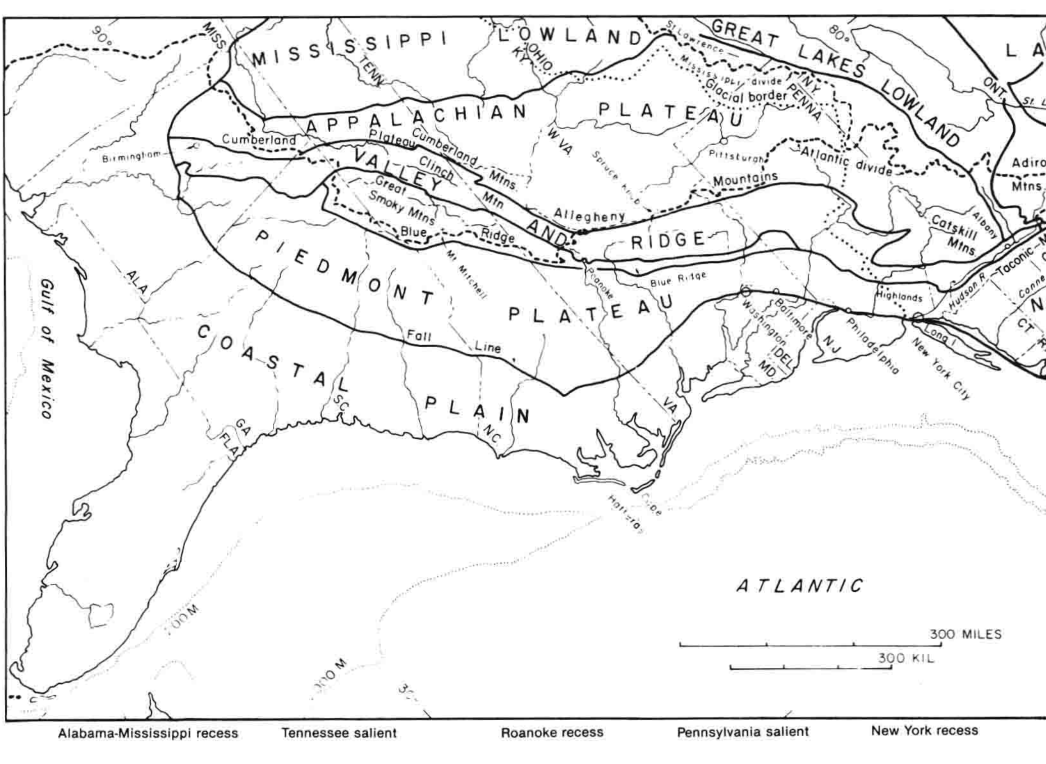


FIGURE 1. Subdivisions of the Appalachian Mountains portion of the Appalachian Orogenic Belt and adjoining regions.

Roanoke or Virginia Recess,
Tennessee or southern Appalachian Salient,
Alabama–Mississippi Recess,
Ouachita Salient,
Central Texas or Llano Recess,
Marathon Salient.

These curves group into three broader major segments of the belt, which have had somewhat different orogenic histories; they are separated by the New York and Alabama–Mississippi recesses and are referred to by the names of the included salient pairs as follows:

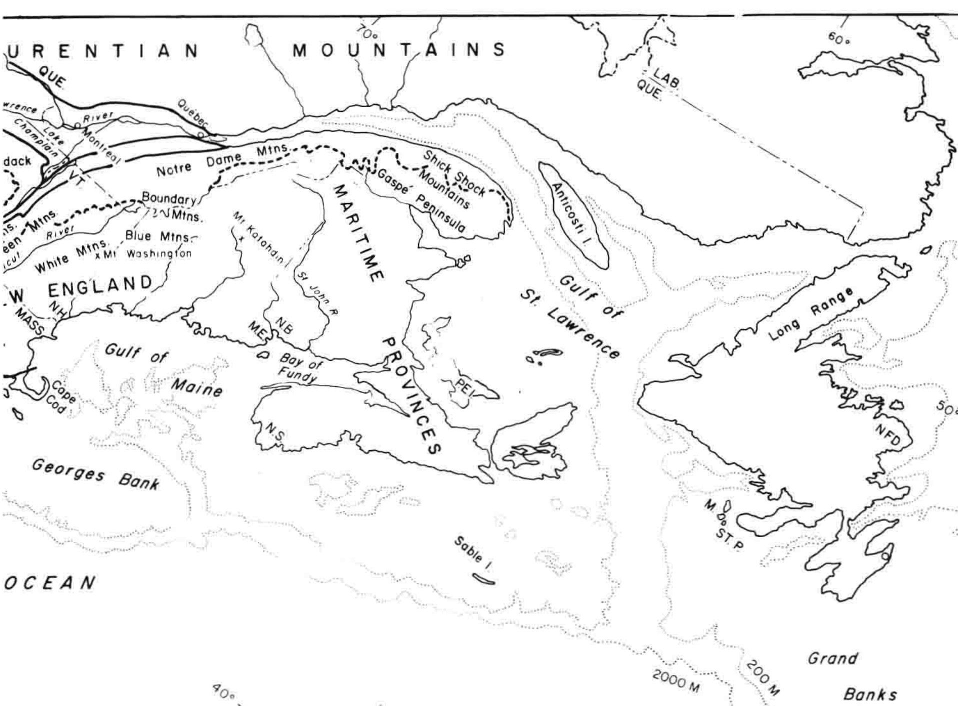
Newfoundland–Quebec Segment,
Pennsylvania–Tennessee Segment,
Ouachita–Marathon Segment.

In the Pennsylvania–Tennessee Segment, a lengthwise subdivision of the chain into belts or tectonic provinces is clearly displayed, from northwest to southeast or from the exterior to the interior of the chain (Fig. 1):

Appalachian Plateau Province: mostly flat-lying upper Paleozoic sedimentary rocks;
Valley and Ridge Province: folded but not markedly metamorphosed Paleozoic sedimentary rocks;
Blue Ridge Province: narrower than the others and not extending to the limits of the segment—an anticlinorium exposing Precambrian basement and lying along the northwest margin of the belt of significant Paleozoic metamorphism;
Piedmont, or Piedmont Plateau, Province: metamorphic and igneous rocks of Paleozoic and perhaps in part Precambrian age, also scattered fault troughs of Upper Triassic–Lower Jurassic continental sedimentary rocks.

Although comparable provinces are less easily distinguished in the other two segments, in them one likewise progresses from unfolded to folded to metamorphosed rocks as one proceeds from the central platform of the continent into the orogenic belt.

In general, sedimentary rocks of each of the Paleozoic systems are relatively thin in the central platform of North America and thicken markedly



Quebec salient Gulf of St. Lawrence recess Newfoundland salient