c20 The standard geologic column < lithostratigraphic, time-stratigraphic >

Hitherto I have never turned a stone; henceforth I will leave no stone unturned . —Sedgwick, appointed in 1818 Woodwardian Professor (dubious honor in retrospect, given John Woodward's woolly geology satirize in 1697 by John Arbuthnot (1667-1735) for its Aristotelian insistence that what is theoretically attractive must actually be true!,[1] although the Cambridge University Chair is by his generous will.[2])

The standard geologic column (***Figure c20.1***) was put together by geologists working in, and from, England during the first half of the 19th century.[3] It acquired its final form after several revisions; each the result of a revolution in geological thought.

At the beginning of the 1800s, the rocks of England and Wales were thought to be correlatable with Werner's proclaimed "universal formations" This was explicitly so of the geologic map of the United States by William Maclure (1763-1840) published in 1809 [4] and in a revised version in 1817.[5]

The first revolution in geological thought that led to the establishment of the standard geologic column was to step back from Werner's grand scheme and to correlate, as earlier had Arduino in Italy (in 1760), the lithologies of traceable beds in detail.[6] The principle of superposition allows beds to be ordered in time. Thus formations (of grossly different rock type) were replaced with the descriptions of strata (lithologically distinctive layers of rock).

A second revolution was the recognition, stemming from Hutton's work, that angular unconformities represent lengthy cessations in what, otherwise, had been a relatively continuous accumulation of strata. Angular unconformities, which are surfaces of no thickness, constitute natural regional boundaries to systems (large time-stratigraphic units) that were named for the lithology of a distinctive stratum in each. The hope was that the named systems that occur in England and Wales are universal. This was soon learned not to be so.

A third revolution was application of Smith's principle of faunal succession to solve the facies problem (*recall* Topic *c17*). Fossiliferous systems could then be shown to have universal significance. When so, the time that a system records is called a *period*. Systems are time-stratigraphic units. Periods are geologic-time units.

A forth revolution was that the location of the *reference* fossiliferous system for a period could be anywhere and where that is (its type area) takes precedence over a poorly fossiliferous local system. The periods were renamed for the type areas of fossiliferous systems.

A fifth revolution beginning in 1837 (*recall* Topic *b15*) was that Diluvium had a glacial origin.

A sixth revolution was the acceptance that angular unconformities are not universal and are not a necessary feature of the boundary between periods. However, this misplaced hope lingered on in the writings of many influential geologists (Kober-Stilleans) well into the last century.

All the above revolutions were before Darwin's theory of evolution became known in 1859. Nor did his theory bear on the following revolution.

A seventh revolution late in the 19th century was the realization that sedimentary and volcanic strata had also accumulated in Precambrian times and that Werner's Primitive formation (as in the Great Lakes area of North America) was divisible using the stratigraphic principle of superposition, "way up" criteria, and the presence of regional angular unconformities and nonconformities.

Subdivision of the Alluvial

Werner's Alluvial, and youngest formation, was characterized by unconsolidated sediments at low elevation. Unconsolidated sediments are geologically young. There is no argument with that where the agent for their deposition is at hand: the river at times of flood, the gravels of its bars, its delta, tidal deposits in wetlands, lake accumulations, and wind-built dunes. "These Buckland designates by the name alluvium," wrote Cuvier in 1825, and, significantly, they "contain only bones of animals native to the territory." Buckland also described, under the name Diluvium (Latin for deluge), older unconsolidated sediments: "layers of silt and argillaceous sand mixed with rounded pebbles from distant places and full of the bony remains of terrestrial animals, in large part unknown or at least strange, seem especially to have covered all the plains, filled the base of all caves, and blocked all cracks in the rocks within their range." These are, Cuvier exulted, "in the eyes of most geologists, the most obvious proof of the immense inundation [the Naochian flood] which was the last of the earth's catastrophes." [7]

Fascination with the problem of the Diluvium, which formation on the basis of superposition could be recognized by its draping hill and dale, led Jules Desnoyers to study it in the Paris basin of France. Its sediments (where they are tills) lack sorting (to the extreme of boulders in clays) and (where they are stratified outwash) contain occasional fossils, strange (cold adapted) in form (mammoth) or out of place (as are the found bones in southern France of reindeer and Arctic birds). In 1829, Desnoyers assigned Alluvium and Diluvium (which latter he, by then, knew occurs in several different layers in Europe and America but is conspicuously absent in low latitudes of the world) to the Quaternary[8] adding this on to Arduino's (presumed older) sequence of three rock units that from their apparent superpositions had come into being sequentially in the formation of the Apennines, Italy. The Quaternary Period became designated to be inclusive of the Holocene Epoch (named in 1885), which is the time since the prehistoric Great Ice Age (as recognized, after 1837, to be recorded by the so-called Diluvium) and the Pleistocene Epoch (named in 1839), which duration is the Great Ice Age.

In 1760, Arduino's had called his youngest formation (composed of unconsolidated gravels, sands, and limestones) the *Tertiary*. Werner later called the same *Alluvial*. In the early 1800s, doubt with Werner's geognosy (that had been applied more on vision than on observation) led John Farey (1766-1826) to use Alluvial for unconsolidated, and Tertiary for consolidated (freshwater mammal-bone bearing, shelly marine, and unfossiliferous) strata in the London and Paris chalk-floored basins.[9]

Beginning in the 1820s, before Desnoyers had commenced his work in France, Lyell in England in collaboration with conchologist Gérard-Paul Deshayes (1796-1875) (who had made systematic collections of Paris Basin fossil mollusks) took it upon himself to subdivided the Tertiary, profiting from Deshayes dawning finding[10] that a statistical study of mollusk species could establish relative ages for its strata. The youngest epoch was recorded by the uppermost strata in which all the these are of yet living species. In 1839, when Lyell named this epoch the Pleistocene "period," he had found it equivalent to the older part of Desnoyers' Quaternary.[11] His subdivision of the Tertiary, published in 1833, was into three "periods." The age of each was indicated by the percentage of is fossil mollusks (clams and gastropods) that continue as living species and which are absent in the oldest "period." The Tertiary fossil succession that he documented he interpreted in accordance to his antiprogressivist stance (***Footnote c20.1***) as due to extirpations and replacements by migrations (*not* extinctions and evolution) as the climate cooled. His "periods" have since been renamed *epochs* and two have been added (*see* Topic *d19*). Also, the Tertiary is replaced (*see* Topic *c22*).

Subdivision of the Flötz (*Figure c20.2*)

The strata of the Flötz underlie the Midlands of England. The more resistant strata of the Flötz are expressed as cuestas (scarps, west facing along the Chiltern and Cotswold hills and inward about the Weald). North of the Weald structural dome, the strata exposed in outcrop dip shallowly east and are, as a consequence, youngest to the east where they emerge in outcrop from beneath the Alluvial. The youngest widely recognized stratum of southeastern England is a chalk of coccoliths with spectacular exposures in the White Cliffs of Dover and the Isle of Thanet. The system that contains the chalk extends into France and is well exposed in the rim of the Paris basin that it underlies. The youngest strata of the Flötz (which contain the chalk stratum) were named the Cretaceous (after the Latin word *creta* for chalk) by **William Daniel Conybeare** (1787-1857)[12] and William Phillips (1775-1829) in 1822 in the key to a geologic map of England published in 1821 by Phillips.[13] A regional unconformity separates the Cretaceous from almost conformable underlying strata that include massive oolitic limestone which is relatively easily quarried and is valued as a building stone. Descriptions of these strata, beginning with Smith's, refer to them as the "Oolitic 'series' or 'group.'" At their top are the Purbeck beds and at their bottom are the Lias (dialectal spelling of layers). The lithological name Oolitic is misleading outside of England because of facies changes. Its fossils, however, allow it to be correlated with fossiliferous strata of the Jura mountains, France. These were originally described by Alexander von Humboldt in 1795.[14] For his type area, the name Oolitic was formally replaced by the name Jurassic.

A regional unconformity at the base of the Jurassic in England separates them from a system of strata of erg and playa lithology originally known as the New Red Sandstone (NRS). That name indicates relative age and was dropped when the reality of facies changes over large distances required geologists to use of fossils for long-range correlations. The upper part of the NRS has almost no fossils. But in the absence of fossils there is still stratigraphic position to go by and its sandwiched position within fossiliferous strata made possible its correlation with the lower part of the fossiliferous Triassic System in Germany that Friedrich von Albert had described and named in 1834. The lower part of the NRS has some reptilian fossils. These allowed it to be correlated with well exposed similar fossiliferous strata in the Urals. Murchison during his 1840-41 tour of Perm province, Russia, had described these and composed the ditty: Ah, the red sandstone! How bored am I! / I'd very well pay a thousand louis / Never again in my life to see / The new red sandstone of [Little] Tartary![15] The lower part of the NRS was then named, for his type area, the Permian.[16]

In England, the Permian rests on a pronounced angular unconformity that cuts across open folds and faults in coal measures that are otherwise thicknesses of alternating sandstones, shales and limestones. This formation was named the "Carboniferous Order" by Conybeare and Phillips in their textbook *Outlines of the Geology of England and Wales,* 1822.[17] The same formation is recognizable in Europe by its stratigraphic position. The coal flora of extinct ferns, "horse-tails" and "scale" trees, is distinctive, but much time passed before its species' ranges were adequately described for system correlations.[18] In the United States, the time of the Carboniferous was found to cover two distinctive formations. Only the younger of these, contains important coal measures. In 1891, Henry S. Williams (1847-1918) described the coal measures that occur in the State of Pennsylvania. He proposed the name Pennsylvanian for them. Its fossils allow it to be assigned to the Upper Carboniferous. Lower Carboniferous in the United states covers the age of limestones exposed in the Upper Mississippi Valley. Because they are not a prospect for coal, the name Lower Carboniferous for them would be misleading. Earlier, for the Lower Carboniferous in America, Alexander Winchell (1824-1891), while director of the Geological Survey of Michigan, had proposed in his (now dated) *Sketches of creation*, 1870,[19] the more suitable name of Mississippian Period for its type section in the Mississippi Valley.[20] This was approved by the U.S. Geological Survey (USGS)—established by an Act of the U.S. Congress in 1879, first Director through to 1881, Clarence R. King (1842-1901).

Conformable beneath the Carboniferous in England and Wales, the basal formation of the Flötz, the Old Red Sandstone (ORS), is a molasse. In Wales, the ORS is mostly unfossiliferous but conformable beneath the Carboniferous elsewhere are lithologically similar alluvial strata that are fossiliferous (vascular plant and vertebrate fossils). Exposures of these in the Rhine valley of Europe were studied by Adam Sedgwick. In 1836, he joined Roderick Murchison in a collaborative mapping (July-August) of Transition rocks (folded graywacke sandstones and shales) in Devon (SW England) that had earlier been studied by J. H. Berger and H. T. De la Beche.[21] Their findings were that the fossils in the Transition rocks of Devon belong to a time before the Carboniferous (no surprise in Wernerian terms for an area with tin and copper mines)[22] but are younger (great surprise but also a relief as in their upper strata are coals) than those which occur in any of the Transition rocks in Wales (which had already long been the focus of their geological field work and in which, in spite of structural complexity, the absence of coals Murchison had shown is a defining characteristic. (In modern understanding, the Late Paleozoic Variscan orogeny domed extensional E-W trending former basins of deposition in which mostly marine graywackes (flysch) had accumulated.)[23] A paper they presented to the Philosophical Society (of London) in 1839, "On the Physical Structure of Devonshire," brought to the fore the importance of considering facies changes.[24] They argued from the stratigraphic position of the ORS and from stratigraphic position of the graywackes of Devon as is indicated by its fossil content that the two systems record the same period (see ***Footnote j7.1***, p. 539). Because the facies change between them occurs beneath the water of the wide Bristol Bay, proof that they were contemporaneous was when a tongue of the fossiliferous Devonian marine strata was later discovered in the ORS in Wales.[25] Both systems record the same duration of time and to advertise the fossiliferous type area it is called the *Devonian Period*. No usefulness remained thereafter for recognizing the Transition formation and the name does not appear in later published geologic columns. Much before then, 'knights of the hammer' (as Geological Society of London Fellows were wont to call themselves)[26] Murchison and Sedgwick had taken it upon themselves to map the Transition strata in Wales.

Subdivision of the Transition in Wales

In Wales, the ORS crops out extensively in the southeast. There this basal unit of the Flötz is open folded (Acadian orogeny). Its strata dip eastward to pass beneath younger strata of the Flötz in southern England. To the west, Transition rocks crop out in mountainous scenery. In Wales, the boundary between the ORS and the Transition is widely, but not everywhere, a pronounced angular unconformity. Where it is, ORS basal conglomerates contain pebbles of Transition rocks and also there the Transition have north-south trending fold axial-plane slaty cleavage (Acadian orogeny).

Roderick Impey Murchison (1792-1871) began his study where his teacher Buckland had found, and close to where Thomas Lewis had shown him, the ORS is conformable upon the Transition. He worked his way down through the Transition strata unfolding these and, using Smith's method, correlating and ordering them "by the evidences of fossils and the order of superposition."[27] The system he described he named the *Silurian* (for a tribe, the Siluries, that had inhabited the area at the time of the Roman conquest). In 1839, he published his first monumental account of the Silurian System. Murchison was knighted in 1846 for his geological contributions. In 1862, he correlated his system with strata in Bohemia.[28] In Wales he was unstoppable in his adding ever older layers of the Transition rock to his Silurian System. These he announced in successive editions of his work *Siluria* (5th ed. 1872).[29] His efforts came to intrude upon the work that Sedgwick had taken upon himself, which was to work upward from the base of the Transition formation.

Adam Sedgwick (1785-1873) began his study of the Transition in the most mountainous part of Wales, which is its north (Snowdonia) and where**,** from Wernerian reasoning, he would surely find the oldest strata in contact with the Primitive. He would work his way up through the Transition strata. The first formation he mapped in detail he called the *Bala Limestone*. In the company of Murchison, he noted that the fossils in these were similar to those of the Caradoc Sandstone Formation in Murchison's field area. However, Murchison used Lyell's statistical method to assign age by fossil content, and the more contorted limestone and slaty nature of the graywacke rocks in Sedgwick's area decided them (by Wernerian reasoning) that these were of different age. The rocks in Sedgwick's field area were not very fossiliferous. To order the strata he relied mostly on lithology and the "strike" (from the German *Streichen*. telling of French geologist Élie de Beaumont's influence)[30] of units to correlate between nearby exposures. Use of the principle of superposition

to order strata was made difficult by their folding (he coined the word *synclinorium* for an area of folds in which younger strata are exposed centrally). Acrimony arose when Murchison changed his mind and made the Caradoc and Bala age-correlatives and then proceeded to add layers below to his Silurian System (the Cambrian is subsumed as his Lower Silurian by 1843).[31] However, in 1852, Sedgwick's paleontological assistant established a clear difference between the faunas in the upper and lower beds of the Carodoc. Also, careful regional mapping found that an angular unconformity (hard to see locally as all is folded) divides the Carodoc and the Bala Limestone Formation.[32] This break in the rock record became the recognized bottom boundary of Silurian in Wales when in 1879 **Charles Lapworth** (1842-1920) formally proposed the name *Ordovician* for the time represented locally by the Lower Bala and Carodoc Formations including a few of the strata in contact below.[33] The name Devonian derives from a Romano-British tribe that once lived in the Bala District of North Wales. Beneath the Devonian is a slaty formation called the *Lingula Flags* and below this are graywackes that contain the distinctive trilobite *Paradoxides*. These were part of the sequence that Murchison had originally included in his *Cambrian* (derived from the Latin name for Wales). And so they are called, which posthumously settles the squabbles of the erstwhile friends. Lapworth working in Scotland, had gained his reputation in 1864 when he showed graptolites to be ideal guide fossils (as are trilobites from the undeformed Transition of Sweden) to distinguish, and subdivide, the Transition strata.[34]

In Wales, during the first field season of his study in 1831, Sedgwick was assisted by Charles Darwin (*see* Topic *c21*) on a fossil hunting foray in his Cambrian System strata. They had no luck then and subsequently the fossils that Sedgwick and others did come to described from the lower part of his Cambrian System are few indeed and these are not distinctive enough to define the type area of the Cambrian to be Wales.[35]

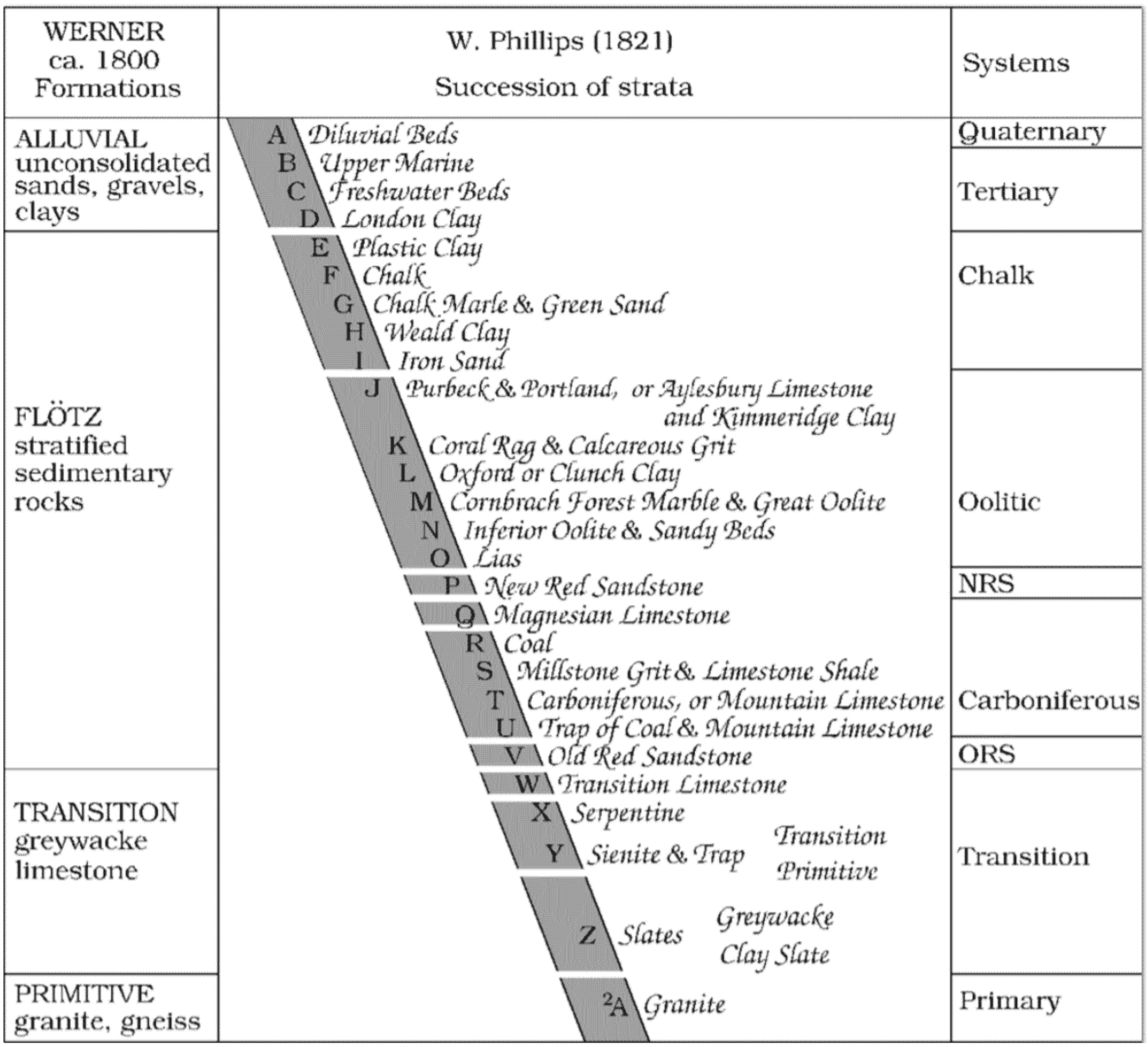
Beginning in 1852, Joachim Barrande described a more complete succession of Cambrian fossils, some distinctive, in Czechoslovakia, that Frederick McCoy and J. W. Salterso could recognize in Sedgwick's type area in Wales for the Cambrian.[36] So, as luck would have it, Sedgwick's Cambrian System, which he had assumed be the oldest from false Wernerian reasoning, does start nearly at the beginning of the accumulation of the very first strata which have fossils of organisms with hard parts that make mesoforms (as archaeocyathids) noticeable in the field when they are present. ❑

Figure c20.1 The initial geologic column was put together during the early 19th century when distinctive rock types were used for correlations. This method is suitable for small areas but facies changes makes it unsuitable for large regions. In the modern geologic column, periods are named for systems that are fossiliferous. The systems are also those in which the fossils were first well enough described to enable the time each covers to be recognized around the world. The names are geographic in that they indicates where the systems can be found. That geographic location is also known as the type area of the system.

(*English mnemonic*: Climbing Over Snowdon, Down Craggy Pass, To Join Camp.)

Early Geologic Column SYSTEMS	Modern Geologic Column PERIODS and SYSTEMS	
Quaternary	Quaternary	
Tertiary	Neogene Paleogene	
Chalk	Cretaceous	
Oolitic	Jurassic	
New Red Sandstone	Triassic	
	Permian	
Carboniferous	Carboniferous	Pennsylvanian
		Mississippian
Old Red Sandstone	Devonian	
Transition	Silurian Ordovician Cambrian	

Figure c20.2 [37] **Episodes in the development of the geologic column in England**
Werner's formations (left column) had become subdivided as portrayed in the key to strata (middle column) in Phillips' geologic map that he published in 1821. In a text he published in 1822 to accompany it, coauthor W. D. Conybeare named subdivisions (systems) of the Flötz for their distinguishing lithologies (right column). This was before the importance of fossils for long-range correlations was known. Fossils would show that these named systems have, because of facies changes, only local significance.



Conybeare and Phillips' *Outlines of the Geology of England and Wales, with an introductory compendium of the general principles of that science, and comparative view of the structure of foreign countries. Illustrated by a coloured map and sections*, 1822, was the most influential textbook on stratigraphy for two decades.

Footnote c20.1 In 1851, leaving Lyell "inebriate with joy," was Patrick Duff's discovery of *Telerpeton elginese* (remote reptile) as named by Mantell—later renamed *Leptopleuron lacertinum* (slender-ribbed reptile) by Owen—in Elgin sandstone of Morayshire which is Devonian if part (and it is) of the Old Red Sandstone.[38] Since 1832, Lyell had entertained that "each species may have had its origin in a single pair, or individual, where an individual was sufficient, and species may have been created [by some natural mechanism] in succession at such times and in such places as to enable them to multiply and endure for an appointed period, and occupy an appointed space on the globe."[39]