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THE MEANING OF CORRELATION

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ABSTRACT. The word *correlation* ordinarily means simply mutual interdependence or interrelation, but when it was introduced into stratigraphy in the later 19th century, it was used to mean the process of determining the time relations of strata. More recently, a broader meaning has been advocated—determining equivalency or continuity in lithology or fauna as well as time relations. These different equivalencies do not necessarily agree, because of facies relationships like transgression, but the criteria used to establish them overlap broadly, and ultimately the acceptability of such criteria depends on their validity in establishing the true time relations. Hence, in stratigraphy, the older narrower definition of correlation should be retained.

A talk that hinges only on the proper use of a word is in grave danger of being both dull and pedantic. Certainly, discussions of real scientific results are far more interesting and entertaining than discussions of words, but not necessarily more important. For we have to express our scientific results in words, and if the words are ambiguous and mean different things to you and to me, they will fail to transmit the results between us. Accordingly I welcome this opportunity to discuss one such word, to explore its current ambiguity as fairly as I can, and yet finally to present, as though it were the logical conclusion, the view I have held all along.

A paper like this loses all its value if it fails to be clear and unambiguous. In my effort to make my meaning as clear as possible, I have been greatly aided by critical reading of the manuscript by the co-chairmen of the symposium, W. Charles Bell, Grover E. Murray, and Laurence L. Sloss, and by my colleagues Carl O. Dunbar, Joseph T. Gregory, John E. Sanders, and Karl M. Waagé. This does not signify of course that they necessarily endorse all or any of my conclusions.

GROWTH OF THE CONCEPT

The word *correlation*, which comes from a Medieval Latin neologism, has wide currency as a technical term in science, but its meaning in stratigraphy is rather specialized and would not be readily guessed by someone unfamiliar with the jargon of the subject. The general scientific usage derives from the grammatical and philosophical meaning of the word—mutual interdependence or interrelation—and reaches its most precise form in statistics, where it is quantified to describe the degree of interdependence of two (or more) variables.

Like many geologic words, correlation in its stratigraphic sense does not seem to have been deliberately introduced but to have crept into use gradually. The Oxford English Dictionary records its use in approximately this sense by R. I. Murchison in 1849, but it was at least very uncommon down to about 1880. In 1888, J. W. Powell, as Director of the U. S. Geological Survey (Powell, 1889, p. 16-17), announced a plan for a series of essays on the "correlation" of the geologic formations of the different systems, and these were published in 1891 and 1892 as Survey Bulletins 80 to 86 under the title Correlation Papers. Powell did not define his use of the word, but he coupled it with "synchrony" and evidently he meant the essays to be concerned with the time relations of the formations. In 1895, J. D. Dana adopted the term in the 4th Edition of his Manual of Geology (Dana, 1895, p. 398, 399), defining "correlate strata" as strata "of the same geologic horizon" (in previous editions he had used the phrase "equivalent strata") and giving a list of "means of correlation"—that is to say, criteria for determining equivalence in age. (By "geologic horizon" he evidently meant about what we would now call time-stratigraphic unit.) During the next decades the word appeared (undefined) in the widely used elementary textbooks by Chamberlin and Salisbury and by Pirsson and Schuchert, "correlation charts" became standard practice in stratigraphic articles, and whole symposia were organized on the subject (see the Journal of Geology for 1909 and the Geological Society of America Bulletin for 1916; the latter symposium was called "General consideration of paleontologic criteria used in determining time relations," but the word "correlation" appears in the title of each of the four articles). Evidently the word had become common coin, and evidently it connoted time relations.

Powell in 1888 (1888; 1890, p. 63-67) drew a sharp distinction between the formations, as cartographic units, and the geologic time units with which the formations were to be correlated. Under the influence of E. O. Ulrich, one of the most influential stratigraphers of the first third of the 20th century, the author of many correlation charts and the inspirer of many more, this distinction tended however to disappear. Ulrich consistently built up the time-stratigraphic framework of his charts out of formations as building blocks, and he and his followers tended to consider the formations themselves as time-defined, mutually exclusive units. Thus stratigraphic correlation came to include the interrelation of formations, defined by time, with each other as well as with an abstract time sequence.

In the 1920's, the petroleum industry began to demand, and to support, more and more stratigraphic work; the extraordinary expansion of stratigraphy under this stimulus is known to all geologists. In the '30s and '40s, moreover, partly under this stimulus, stratigraphers revived the sharp distinction between, on the one hand, the formation or mapping unit defined on rock type alone (rock-stratigraphic unit) and, on the other, the unit based on time, by whatever means time relations may be determined (time-stratigraphic unit). In the process the term *correlation* has been pulled two ways. One group of geologists wishes to return more nearly to the original usage and restrict the term to time relations; the other group wishes to include under the term all kinds of interrelations of formations and other units—not just those of time. The divergence may be illustrated by two definitions from recent textbooks: "Correlation is the process by which stratigraphers attempt to determine the mutual time relations of local sections" (Dunbar and Rodgers, 1957, p. 271), and "Stratigraphic correlation is the demonstration of equivalency of stratigraphic units . . . in terms of lithologic or biologic continuity or in terms of the geologic time scale" (Krumbein and Sloss, 1951, p. 287). And, carrying the second point of view even further, Shepard Lowman (1949a, p. 147-151; 1949b, p. 1967-1971) has protested vigorously against any use of time-terminology in stratigraphic correlation, which he prefers to express only in terms of "stratal or faunal continuity." I take it this controversy is what I am asked to discuss, and my known reactionary views on the subject the reason I was asked to discuss it.

THE CRITERIA OF CORRELATION

Before discussing it, however, I would like to consider how we establish correlation, whether that term includes for us stratal or faunal continuity without reference to time or only time relations. There is no need to list all the available criteria or to evaluate them; that is done in the textbooks referred to and elsewhere. Two main classes of criteria are generally recognized: the lithologic and the biologic.

Most of the lithologic or physical criteria are in essence attempts to trace beds, groups of beds, members, or formations, to establish "stratal continuity" whether for its own sake or in the belief that it tells us at least something about time relations. Individual beds of certain special kinds, as for example a bed of volcanic ash, or individual beds with certain special peculiarities, as for example a limestone bed with unique chert nodules in its upper third, serve the best, as far as they are traceable and distinguishable from similar beds above and below (for even the most peculiar bed represents a particular depositional environment that might be repeated). Beds of more banal rock types, however, are not ordinarily distinct enough to be traced and kept separate from the adjacent beds, and it is notorious that the boundaries of members and formations need not remain parallel to either individual beds or assumed planes of contemporaneity, and indeed rarely do, if followed across regional facies trends, though they may exhibit a sort of "stratal continuity" if the intertonguing of facies is not too deep. Finally, the ultimate limit of all these criteria is the limit of traceability of the beds or grosser units—in general, the limit of the individual basin of deposition.

One subclass among the physical criteria stands apart from the others—namely, radioactive age determinations, calculated from measurements of parent and daughter elements or isotopes. No question of continuity is involved here; only the comparison of independently determined, absolute ages, generally rounded off to millions of years. The individual ages so determined are still imprecise, because of analytical difficulties and difficulties in calibrating the different age methods with each other, and still relatively scarce and erratic in distribution, because of the rarity of suitable materials and the time, care, and expense required for first-rate determinations. Radioactive methods therefore, though they provide invaluable information on absolute ages, are of little or no value in correlation—the determination of relative time relations—except where biologic criteria are wanting, as in the Precambrian or in metamorphic terranes, or where the dates can be determined in thousands instead of millions of years, as in the latest Pleistocene.

The other main class comprises the biologic or paleontologic criteria. Now fossils may be used as criteria of correlation in two ways—either simply as intrinsic peculiarities of the rocks that contain them, commonly reflecting faithfully the environments that produced the rocks, or as the expression of an irreversible time sequence, the sequence of life forms produced by organic evolution. Actually, most stratigraphers in most problems use them in both ways at once. If used in the first way alone, they differ from lithologic criteria only because they are more varied and have more special peculiarities than mineral grains or rock types; what is attempted is the same—the establishment of the continuity and, hopefully, the contemporaneity of beds or groups within individual basins of deposition—and the pitfalls are also the same—mainly facies changes that invalidate the assumed continuity or contemporaneity. Because there may be several different kinds of fossils affected differently by changes in environment, more kinds of criteria are available for detecting the facies changes and establishing the true relations, but the principle is the same as with lithologic criteria.

But once fossils are considered as evidence for the evolution of life through geologic time, a vast extension of their use becomes possible, for that sequence, quite unlike the sequence of rock types[1], is irreversible; fossil forms appear in a determinable order, and once extinct they never reappear. Fossils, and fossils alone, have made it possible to determine the relative ages of rocks on different continents to the degree of precision to which we are now accustomed; in effect, they alone have made other than local stratigraphic correlation possible. The extent of this precision in long-range correlation is quite exactly expressed by our practical time-stratigraphic terminology, which was indeed developed to express it; thus the geologic eras and systems have been recognized throughout the world (though with some difficulty locally in entirely non-marine deposits like those of the Karroo basin of South Africa); series and stages are almost equally world-wide in certain parts of the record where the fossils are particularly well adapted to precise correlation (as in the Jurassic system with its ammonites and the black shale facies of the Ordovician with its graptolites), but are only continental or provincial in other parts; and zones are mainly provincial in extent, with some exceptions.[2]

Although the two uses of fossils can be kept conceptually distinct, they

[1] Fairbridge (1954) has suggested that certain rock types, mainly among the carbonates, may be confined to particular geologic systems though present on several continents, so that they also may be considered to form an irreversible sequence and hence to permit world-wide lithologic correlation. Virtually all these rock types are biogenic, however, and reflect the progress of organic evolution; even if such correlation is possible, the exception is less glaring than at first appears. Radioactive age determinations are another exception, but, as noted above, they permit at present only rather gross "correlation."

[2] I still stubbornly persist in my belief that zone, stage, series, and system are all the same kind of stratigraphic unit, whatever that kind of unit may be called, and in my rejection of the currently popular distinction betwen time-stratigraphic and biostratigraphic categories of units. All agree that zones (in the sense in which the term was first used in stratigraphy by Oppel; nowadays some prefer to call these faunizones, assemblage-zones, or cenozones) are defined by assemblages of fossils. But stages have been defined in precisely the same way ever since the term was first introduced by d'Orbigny, by assemblages of fossils, and likewise beds can be assigned to a given series or system (except in the trivial case of beds near the type locality) only if fossil evidence of some kind can be found, either in the beds in question or in others near enough so that the local stratigraphic relations are reasonably clear. In the absence of fossils, no assignments as precise as system can be made, only such vague ones as pre-Triassic or Precambrian, which themselves merely state that the rocks are older than the oldest fossiliferous rocks in the particular region. If time-stratigraphic units are to be *defined* as units "fundamentally independent of all physical, objective properties of the rocks," then (a) such units have no practical value in stratigraphy, and (b) system, series, and stage, as used every day by stratigraphers, have never been and are not now such units, any more than zone is. For further arguments pro and con, compare Rodgers, 1954, and Hedberg,1954.

are not easily (nor commonly) separated in practice. The stratigrapher studying the fossils of an area uses them both to determine the interrelations of the beds within the area and to correlate those beds with the standard time-stratigraphic sequence, i.e. with beds of the same age on the other continents. The difficulty is that the same fossils may be of different value for the two different tasks; fossils that mark excellent local "key beds" may be very long-ranging elsewhere, whereas fossils that may be significant in determining what series or stage is represented may be strongly influenced by facies and hence deceptive for local use. Most commonly perhaps, the fossils are not perfectly adapted to either use, and different fossil groups give contradictory results because differently influenced by the facies. These situations can become very frustrating, and can lead to the view that, since fossils are fallible criteria of correlation, paleontologic correlation is fallacious. But what the frustration proves is rather that we are using an intrinsically good tool at the limits of its range of usefulness, like a microscope used to look at objects barely larger than the wave length of light. For local correlation, fossils are only one of several tools available, of which now one is more useful, now another; we would be less than intelligent to refuse the help of any of them in solving the difficult problems before us. For general correlation, fossils are much the best tool we have, and we should spend our energies not griping about the tool's deficiencies but trying to sharpen it by more and more careful work on the fossils themselves, with special emphasis on their stratigraphic variations, in short by more monographic studies of fossil faunas.

APPLICATION TO AN EXAMPLE

But let us get back to our subject, the meaning of correlation, and examine it in terms of a particular stratigraphic example. The Cambrian strata of the Grand Canyon (fig. 1) display one of the best documented and most straight-forward cases of facies shifts in the record, a veritable "textbook example"—now that the painstaking work of McKee (1945) has made it clear for us. In any one section three chief rock types occur in sequence—at the base virtually unfossiliferous sandstone, in the middle trilobite-bearing shale, and at the top carbonate rock with sparse fossils in a few beds. These were early distinguished as separate formations and given geographic names; apparently it was tacitly assumed that each was of roughly the same age throughout, for each can be readily traced from one end of the Canyon to the other. McKee's work showed, however, that they record three major facies transgressing eastward one above the other, though with minor regressions at intervals, and that the Bright Angel shale is all or virtually all Lower Cambrian at the west end of the Canyon but all Middle Cambrian at the east end.

What then is the "correlation" of the Bright Angel shale? If we take the term in the broader sense, there are several. Clearly the shale unit is continuous throughout the Canyon, and on this basis the shale at the east end "correlates" with the shale at the west end. If individual beds in the shale could be traced, however (as by walking out key beds or by matching kicks in electric logs in closely spaced wells, assuming key beds or kicks were present), presumably the facies change would be detected, and on this basis

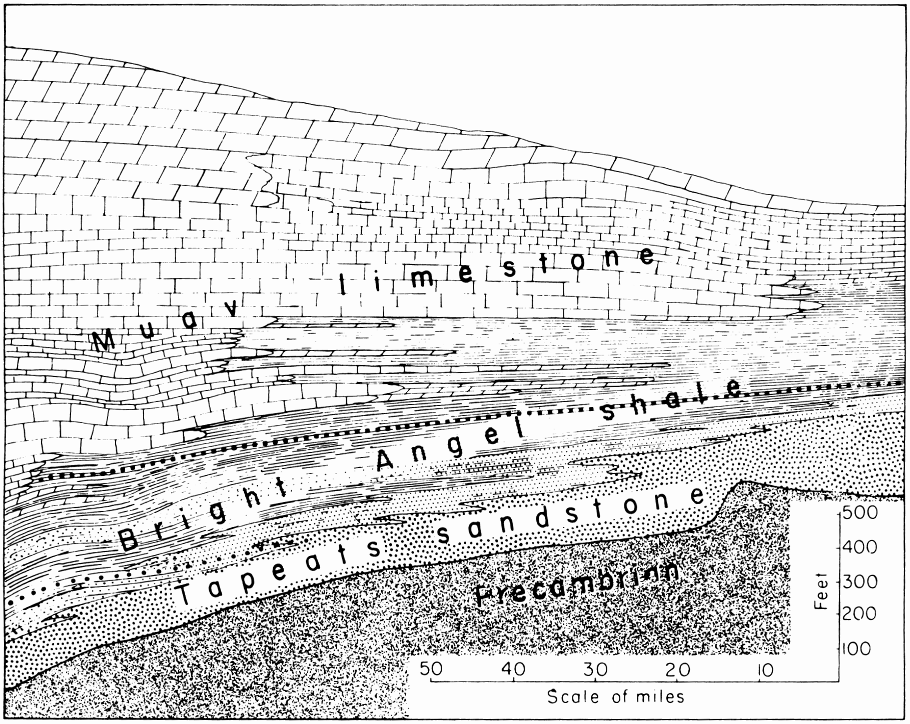

Fig. 1. East-west section of the Cambrian formations exposed in the Grand Canyon of the Colorado in northwestern Arizona. Drawing by C. O. Dunbar after E. D. McKee (1945). Stratification lines indicate isochronous deposits. The row of heavy round dots marks a high Lower Cambrian faunal zone (*Olenellus*); the row of heavy square dots marks a low Middle Cambrian faunal zone (*Glossopleura*). Reprinted with permission from Dunbar and Rodgers, 1957 (fig. 73, p. 141), John Wiley & Sons, Inc.

the shale at the east end would "correlate" with the lower part of the Muav limestone at the west end. Yet both "correlations" are based on "stratal continuity." Similarly, if the fossils were not studied with care, the trilobite fauna in the shale at the east end might be "correlated" by biologic continuity with that in the shale at the west end, but a trilobite specialist would soon discover that new forms invaded the shale during the transgression, and he would prefer to correlate the fauna in the shale at the east end with the sparser fauna in the limestone at the west end. Finally, in terms of time, the older idea was that the shale was contemporaneous throughout, but McKee, by careful attention to the distinction between transgressive and regressive phases and by tracing key beds and fossil zones, showed that correlation to be incorrect and replaced it by another.

Thus in each case two possible correlations are offered, but only time, it seems to me, provides a clear-cut basis for choosing one over the other. If we choose the stratal continuity of individual beds instead of the more obvious stratal continuity of the shale unit, we do so because we think the beds are more likely to be contemporaneous throughout than the formation. Similarly, if we reject "facies fossils" and correlate instead by the few that cross facies boundaries, we do so because we think the latter are more significant timewise. Ultimately, in other words, we evaluate our criteria of correlation by their usefulness in demonstrating the true time relations.

But apparently the idea of having more than one "correlation" for the same unit bothers some people less than me. Krumbein and Sloss (1951, chap. 10) distinguish three different kinds of "correlation" in terms of the different kinds of stratigraphic units correlated and the different kinds of criteria used. Thus rock-stratigraphic units are to be correlated "in terms of lithologic . . . continuity" by lithologic criteria, and similarly biostratigraphic units, whereas time-stratigraphic units are to be correlated "in terms of the geologic time scale" by time-stratigraphic criteria listed separately from, and apparently distinct from, the lithologic and biologic criteria, or rather from the criteria for lithologic and biologic correlation. But surely this neat separation is contradicted by every real example of correlation. Working out the true lithologic relations ("stratal continuity") of the rock formations in the Grand Canyon was greatly aided by if not entirely dependent on working out the fossils; on the other hand, the true biologic relations of facies faunas may only be recognized because lithologic criteria suggest the intertonguing of two rock types carrying different fossils. And above all, the establishment of the mutual time relations of stratigraphic units of any kind involves every possible criterion of correlation, not just certain ones; we would be remiss if we ignored any of them, though different criteria may be more useful in different problems. Thus it is perfectly proper to speak of the correlation of two rock-stratigraphic units (formations) in terms of time, and the criteria by which this correlation is established may be a mixture of lithologic, environmental biologic, and evolutionary biologic criteria. And when one speaks of the correlation, i.e. equivalency, of two formations in terms of lithologic continuity, either one is simply saying that they hold the same relative position among shifting facies, or one is suppressing the premiss that they are equivalent because they are contemporaneous.

Accordingly, to no one's surprise, I conclude that in stratigraphy the term *correlation* should and in fact ordinarily does mean the attempt to determine time relationships among strata, however they may be divided into stratigraphic units, and that all the criteria of correlation, imperfect though they may be, are means to this end. It may be more honest, as Lowman has urged, to state our conclusions in terms of the actual criteria rather than in terms of the assumed time relations, but the very reason we accept these criteria and not others is that we hope they will lead us to understand the time relations. Understanding the relationships of continuous units that transgress time is part of understanding time relations, but, once we understand the transgression, to say that two non-contemporaneous parts of such a unit "correlate" only confuses the issue; their relation is that of facies equivalence. Otherwise we will take a word that has had a fairly precise meaning in stratigraphy and turn it into a source of ambiguity, so that we misunderstand each other even more than at present and interpose an unnecessary, dull, and manmade difficulty to distract us from the really interesting problems, the ones in the rocks themselves.

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