Thomas Goldstein (U.S.A.)

THE INFLUENCE OF THE GEOGRAPHIC DISCOVERIES UPON COPERNICUS*

The history of geographic thought is rarely considered as an integral part of the history of science. We are inclined to think of the geographic discoveries primarily in terms of a dramatic "adventure story", an explosion of dynamic energies released by the culture of the Renaissance, and what theoretical achievements we may be ready to concede to that collective enterprise seem largely unconnected with the immediately following burst of intellectual energies which marked the rise of modern science, the Scientific Revolution. If this lack of meaningful connections between the emergence of the early modern universe and the preceding cultural and practical-scientific movements should indicate our present inadequacy in relating the Scientific Revolution to the general historical context, this basically "unhistorical" approach is highlighted even more sharply by an unsolved historical problem in the evolution of theoretical science itself: Historians of science have long been puzzled by the apparent gap which extends between the advanced cosmological insights of fourteenth century thinkers and the actual formulation of the sun-centered cosmos, almost two hundred years later, by Nicholas Copernicus (or the physical, mathematical and astronomical implementations of the heliocentric system through his successors, which crystallized after an even much longer time). Indeed, so many basic aspects of the modern universe had been anticipated by fourteenth century cosmologers like Jean Buridan, Albert of Saxony or Nicole Oresme (or the mathematicians of Oxford's Merton College) that one must not only wonder why it took these brilliant insights such a long time to mature, but also why the flourishing of Renaissance culture should have acted as a major inter-

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ruption in the continuous growth of cosmological thought. Should we assume that the Renaissance "absorbed" the best creative energies with its artistic and literary–esthetic interests, so that they were only able to "revert" to the great cosmological problems after the Renaissance had run its course? Such vague, semi-biological assumptions are hardly the stuff of serious historical scholarship. [1] Besides, the Renaissance no longer looks to us like an exclusively artistic (or esthetic) culture. Even though its scientific contributions have not yet been satisfactorily explored, we have begun to recognize that it contained important undercurrents of scientific thought and that in fact even its art — beyond the phenomenon of Leonardo da Vinci — involved some vital scientific aspects in anatomy, perspective, optics and, conceivably, in certain more fundamental areas as well. [2] For all its fervor of creative passion the temper of the Renaissance no longer seems as alien to systematic scientific studies as it did a hundred years ago. Why should its flowering have interrupted the steady growth of cosmological thought between the fourteenth and the middle of the sixteenth century?

The fact (as I shall try to demonstrate) is that it did not. Quite on the contrary, the most outstanding scientific contribution made when Renaissance culture was at its height — the geographic discoveries and the changed concept of the earth which they produced — provided sixteenth

[1] The idea that the Renaissance (or Renaissance humanism) interrupted the continuity of science is pointedly expressed, *e.g.*, in J. H. Randall, Jr., *The Making of the Modern Mind*, Cambridge, Mass., 1940, p. 212, in an otherwise well-informed discussion of late Medieval and Renaissance science: "For natural science humanism was an almost unmitigated curse. Had it not centered the energies of the best intellects on the essentially non-scientific wisdom of the [...] Romans, these vigorous scientific interests [of the later Middle Ages] might have produced a Galileo long before the seventeenth century." Also H. Butterfield, *The Origins of Modern Science, 1300–1800*, New York, 1962, p. 21: "Indeed, Galileo could have produced much... that we find in his juvenile works [on the subject of *impetus*] if he had lived during the 14th century; and in this field one might very well ask what the world with its Renaissance and so forth had been doing in the meantime." T. S. Kuhn, *The Copernican Revolution*, New York, 1957, pp. 127 ff., gives what amounts to an interesting explanation for the "time lag" in terms of the influence of Renaissance Neoplatonism on Copernicus (and Kepler). For the spadework of fourteenth cent. science, e.g., H. Butterfield, *op. cit.*, ch. 1: "The Historical Importance of a Theory of Impetus"; T. S. Kuhn, *op. cit.*, pp. 115 ff; or E. A. Moody's highly informative essay, *Laws of Motion in Medieval Physics*, in: *Toward Modern Science*, ed. Robert M. Palter, New York, 1961, I, pp. 220 ff.

[2] I have attempted a brief summary of recent scholarship on the scientific aspects of the Renaissance in my *Geography in 15th Cent. Florence*, in: *Merchants and Scholars*, ed. John Parker, Minnesota University Press, 1965, pp. 11 f. (with bibl.). See also Joan Gadol, *The Unity of the Renaissance: Humanism, Natural Science and Art*, in: *From the Renaissance to the Counterreformation, Essays in Honor of Garret Mattingly*, ed. Charles H. Carter, New York, 1965, pp. 29–55 (reprinted in *The Scientific Revolution*, ed. V. L. Bullough, New York, 1970); J. Gadol, *Leon Battista Alberti, Universal Genius of the Early Renaissance*, Chicago University Press, 1969. Renaissance contributions to the Copernican astronomy are discussed briefly in T. S. Kuhn, *op. cit.*, pp. 123 ff. (esp. p. 129, on Domenico Maria de Novara; also L. Sighinolfi, "Dom. Maria Novara e Nicolò Copernico", *Studi e memorie per la storia dell'università di Bologna*, vol. V, 1920, no. 2, pp. II–35); and D. Hellman, "Science in the Renaissance. A Survey", *Renaissance News* (Ren. Society of America), vol. 8, no. 4, Winter 1955.

century cosmologers with an important empirical element that had been missing in fourteenth century science, with the result that early modern science was able to proceed upon a basis of empirical certainty, where the late Middle Ages had been confined to an essentially abstract type of reasoning, or pure, inspired speculation. The principal evidence for this presents itself through an analysis of one of the opening chapters of Copernicus' *Revolutions of the Heavenly Spheres* (Book One, ch. 3), in which Copernicus offers a remarkable interpretation of the new concept of the earth that had resulted from the recent geographic discoveries, proceeding to use the "new earth", in a perfectly concrete and visual way, as a stepping stone for his heliocentric theory, a tangible foundation for his ascent towards the new cosmos. By interpreting the meaning of his geographic chapter, in other words, I believe one finds that the age of the Renaissance, instead of interrupting the continuity of cosmological thought, had contributed a crucial element to Copernicus' conceptual process — as well as, through his introduction of the new concept of the earth, to the thinking of his successors in the Scientific Revolution. What is more, such an analysis reveals Copernicus' grasp of physical problems and his, on the whole, consistent logic in dealing with the non-astronomical premises of his system to a far greater extent than he is as a rule given credit for by modern historians. [3]

Copernicus' geographic chapter (including his reference to the recent discoveries) was brought to the attention of scholars in an article by Edward Rosen, published in 1943, with the suggestion that he had formed his geographic concepts from Johannes Waldseemueller's *Cosmographiae Introductio* of 1507. While I do not agree with every one of his arguments in this context, I tend to accept Professor Rosen's suggestion that Waldseemueller's *Cosmography,* including its map work, was Copernicus' principal geographic source. [4] On the other hand, since the chapter implies that he had formed his ideas by actually studying a map which represented the new picture of the earth, he may well have derived (or at any rate confirmed) his ideas from the study of any one of several world maps of the new type that were available by 1512, when he seems to have begun to work on the *Revolutions* and in all likelihood wrote the opening chapters. [5] It may be noteworthy that in his *Com-*

[3] See below regarding Copernicus' intrinsic logic in dealing with the non-astronomical premises of his system, as well as his physical ideas; also, briefly, for the influence of his concept of the earth on his successors. Copernicus' alleged failure to cope logically with the implicit physical problems: T. S. Kuhn, *op. cit.,* pp. 148 f.; H. Butterfield, *op. cit.,* ch. 2: "The Conservatism of Copernicus" (esp. pp. 41 ff.).

[4] E. Rosen, "Copernicus and the Discovery of America", *The Hispanic-American Historical Review,* May 1943, pp. 367–371. The most telling of Rosen's arguments is that Copernicus used the name "America" and speaks of it as a "land named after the Captain who discovered it".

[5] On Copernicus beginning his work on the *Revolutions* during his stay at Heilsberg castle or at Fromburg, about 1512: A. Armitage, *The World of Copernicus* (origin-

mentariolus, written as a short summary of his basic astronomical thesis, presumably while he was setting out on his work on the *Revolutions,* Copernicus omitted any references to the new geographic concepts. However, even there he clearly operates with a concept of the earth as rotating "together with its circumjacent elements" — or "together with its circumjacent waters and encircling atmosphere" — which is the salient, and decidedly anti-Aristotelian, idea he developed in the *Revolutions* from the new geographic evidence. He may have reserved a more explicit geographic elaboration "for my larger work", as he did "for the sake of brevity" with respect to his mathematical demonstrations; or else his concept of "our sphere" in the *Commentariolus* may still have lacked the full compactness that it achieved in the *Revolutions* — a possibility which suggests itself as the more plausible one from his repeated phrasing. [6]

At any rate, it is not suggested here that geographic considerations

ally: *Sun Stand Thou Still,* 1947), Mentor Books, New York, 1951, pp. 74, 78. The geographic chapter as a whole is evidently based on the ideas formed from visual evidence (*cf.* the interpretation below). Some arguments are moreover directly derived from the study of a map (*e.g.* that there is a "passage barely 15 stades wide" between the "Egyptian Sea and the Arabian Gulf, well-nigh in the middle of the great land mass"; or that "geometrical argument demands that the Mainland of America on account of its position be diametrically opposite to the Ganges basin in India" — which presupposes that Copernicus visualized a world map as being transferred upon a globe, presumably by measuring the distances). Examples of world maps showing the New World which were published up to 1512 would include the Cantino world map of 1503, or the Contarini world map (*e.g.* in the 1506 engraving), or Joannes de Stobniza's of 1512 (see note 23 below).

[6] A. Armitage, *op. cit.*, p. 74, places the date of the *Commentariolus* about 1512 "or a little earlier"; E. Rosen, *Three Copernican Treatises,* Columbia University Press, 1939 (2nd ed., Dover Publications, New York, 1959), pp. 7, 59, points out that no definite date can be assigned to the *Commentariolus,* but agrees that it was written while he was planning, or beginning work, on the *Revolutions.* That the *Commentariolus* generally represents an earlier phase in Copernicus' thinking than the *De revolutionibus* is evident from the nature of its heliocentric theory (E. Rosen, *op. cit.*, p. 7). I am inclined to assume a similar progression for his concept of the earthly sphere because in the *Commentariolus* Copernicus speaks of the "motion of the earth and our sphere" (p. 59); or a little later, of "the earth[rotating] *together with its circumjacent waters* and encircling atmosphere" (p. 63), *i.e.* in both instances assuming an apparent distinction between the earth itself and the "sphere" as a whole, including its pertinent elements. Since I find no evidence for Rosen's interpretation (p. 58, n. 4) that Copernicus already in the *Commentariolus* had conceived of water as effectively integrated with the globe (and therewith confined to its surface), I believe it is reasonable to assume a conceptual progression from the essentially mathematical idea of the "sphere" in the *Commentariolus* to the concept of the globe as a physical body, based on geographic evidence, in the *Revolutions.* I think this progression (and the final adoption of the concept of the sphere as a three-dimensional body in the opening chapters of the *De revolutionibus*) holds true despite Rosen's very careful argument (p. 11 ff.) that Copernicus was ambiguous in his use of the Latin terms corresponding to "sphere" as a three-dimensional body and as a two-dimensional circle or as a purely mathematical concept (*sphaera, orbis, circulus*), and that he "avoided taking sides in the controversy over the question whether the spheres were imaginary or real" (p. 11). What Rosen is here discussing is the nature of the spheres to which the planets (according to the Aristotelian tradition) are supposed to be attached, not the shape and nature of the earthly globe. I believe to be able to show below that in the opening chapters of the *De revolutionibus* Copernicus introduced the concept of the earth as a physical body, including water, and proceeded to operate with this concept in his subsequent arguments. (The text of the *Commentariolus,* in Rosen's English translation, is printed in

were in any sense a primary factor in causing Copernicus to revise the geocentric system. His motivations were first of all mathematical, as he himself stated clearly in the introduction of the *Revolutions* (though even there his phrasing reflects rather definite Renaissance influences, in this instance of an esthetic order).[7] Nevertheless, the role of the new picture of the earth in Copernicus' thinking seems so significant, precisely because it permitted him to visualize his rotating earth in concrete physical terms, rather than merely as a theoretical mathematical hypothesis which he tried to substantiate through astronomical evidence: Until the earth could be conceived as a "solid" sphere, its rotation would have had to be imagined in the physically prohibitive terms of the Aristotelian cosmology, in which the various elements occupy their own separate and by definition stationary "spheres" — so that Copernicus' innovation would in essence have come down to a mere matter of optical relativity (*i.e.* the inner core of Aristotle's cosmos rotating around itself, as well as the sun, instead of the universe rotating around that inner core). This — as well as any other conceivable alternative — would have raised virtually insuperable difficulties within the accepted system of Aristotelian physics, reducing the Copernican theory to little more than a physically unsubstantiated mathematical abstraction, which is exactly of what he is often accused by modern historians.[8] Yet the new geographic concepts enabled him in fact to think of the earth in the

Three Copernican Treatises). The reference to the earth rotating "together with its circumjacent elements" occurs at least twice (pp. 58, 63); the reference to the "larger work" in which Copernicus promises to supply the mathematical demonstrations is on p. 59.

[7] In his Preface to the *Revolutions,* dedicating the work to Pape Paul III, Copernicus blames the various geocentric explanations for their lack of a uniform underlying principle and goes on: "With [these mathematicians] it is as though an artist were to gather the hands, feet, head and other members for his images from diverse models, each part excellently drawn, but not related to a single body, and since they in no way match each other, the result would be monster rather than man" (quoted from the Engl. translation in T. S. Kuhn, *op. cit.,* p. 139). For Kuhn's discussion of Renaissance–Neoplatonic elements in the *De revolutionibus,* see note 1 above. A perceptive discussion of Pythagorean elements in Copernicus thought, in relation to its musical implications and affinities, was given in a paper by W. Voisé, *Nicolas Copernic, Histoire d'une découverte,* at the XIIIth International Congress for the History of Science in Moscow, 1971.

[8] See note 3 above for modern criticism of Copernicus' alleged failure to cope with the implicit problems of Aristotelian physics. The primary physical difficulty in his heliocentric theory would seem that it violated Aristotle's laws of motion by implicitly separating the earth from the center of the universe, and by implying a circular motion for the earth as well as its "circumjacent elements", plus a planetary motion for both, while the spheres of the elements in Aristotelian physics are generally conceived as stationary, as the sites where the natural motion of the elements comes to rest (although Aristotle introduces certain qualifications of this idea in the *Meteorology*); and while natural circular motion is reserved for the "celestial region" (and therewith precluded for the "sublunar region"). Copernicus (*De rev.,* I, 8) argues specifically for the possibility of rectilinear and circular motion in evident reference to the earth and its "associated" elements (or in other words to Aristotle's "sublunar" region), and even more specifically for the possibility of circular motion as natural to a body's state of rest (see below, esp. note 26) for a survey of what I consider Copernicus' intrinsically logical attempt to modify Aristotelian phisics so as to accomodate his rotating earth, thereby opening the way for the fundamental revision of Aristotle's physical system).

modern sense of the earthly globe, thereby for all intents and purposes subverting Aristotle's physical cosmos and, however implicitly, paving the way for the early modern system of universal physics. [9]

In the Aristotelian cosmology the concept of an earthly globe as an integral physical body had been submerged by his famous hierarchy of concentric spheres, which not only divided the globe into the separate "spheres" of the element earth and water but, by the same token, held the earth so firmly tied to the center of the cosmos that any idea of the globe's moving across the universe as a planet would have been effectively precluded. In what was probably the most succinct formulation of his cosmic vision Aristotle, in Book IV, ch. 5 of the *Physics*, had stated: "The earth rests inside the water, the water inside the air, [the air again] inside the ether, and the ether inside the sky, but the sky is no longer [contained] inside anything else." [10] Even though he had of course considerably expanded (and to some extent modified) this classically simple vision, especially in the *Meteorology* and the *De coelo*, one might consider this almost poetic statement as an apt summary of the cosmological system he was to bequeath to the next two thousand odd years. [11] And it was in essence of this vision with which a long line of Medieval commentators was to wrestle and which confronted Copernicus, as he set out to revise the geocentric cosmology.

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[9] See notes 25, 26 below. T. S. Kuhn, *op. cit.*, p. 146, already observed that Copernicus in his geographic chapter wished to demonstrate that the globe is made up of solid matter and that water is part of the earthly sphere. Yet in making this point rather casually, Kuhn omitted an explicit interpretation of the geographic content of the chapter and failed to recognize its significance for Copernicus' physical thought (accusing him in sequence of his "conservative" adherence to Aristotelian laws, p. 148). In the same way — *i.e.* by interpreting the basic meaning of the chapter only by a casual remark — Kuhn fails to place the chapter in its proper historical context, *i.e.* as a conscious contribution to the long-standing debate about the structure of the earth (see below and notes 17, 18).

[10] "Ether" (αἰθήρ) is sometimes used for the fiery element already by Homer; cf. Kirk-Raven, *The Presocratic Philosophers,* Cambridge University Press, 1971, p. 10. Aristotle offers a similarly terse formulation in the *De coelo,* II. 4 (Loeb Classical Library, Cambridge, Mass., 1939, p. 161; translated by W. K. C. Guthrie): "One might also be brought to this belief [*i.e.* that the heavens are spherical] by the consideration of the bodies situated around the center; for *if water is found around the earth, air around the water and fire around the air,* the upper bodies will follow the same arrangement... *But the surface of the water is spherical."*

[11] Aristotle's general doctrine of the four elements is in *De coelo,* Books III–IV; also: *De generatione et corruptione,* Book II. His *Meteorology* (in discussing origins and transformations of physical phenomena) contains a number of rather amazing modifications, *e.g.*: "We call air the part which immediately surrounds the earth" (*Met.,* I, 3; Loeb Class. Library, 1952, p. 21; transl. by H. D. P. Lee); or, when speaking of the river Ocean of the ancients as a "river with a circular course, which rises and falls and is composed of a mixture of water and air" (*Met.,* I, 9; p. 71). The editor's "Introduction" (pp. XXIII ff.), discusses the place of the *Meteorology* in the corpus of Aristotle's writings and suggests it may have been a late work. Medieval commentators, in discussing the structure of the earth, often liked to refer to the *Meteorology,* and seem in fact to owe many of their modifications of the unqualified theory, as presented in the *De coelo,* to that work (see, *e.g.,* note 18 below). But the influence of the resp. Aristotelian works on the Medieval debate might need closer investigation.

There are several significant implications to this cosmic vision which are relevant in this context — as they must indeed have been relevant for Copernicus' thought: First of all, the Aristotelian system was by no means an arbitrary one. Rather, its order was based upon ostensible common sense. Out of the various features which he had taken over from his Greek (or earlier ancient) predecessors, Aristotle had constructed a seemingly rational system that agreed completely with the naive, everyday observation of the surrounding universe. To such naive observation (confirmed by the geographic concepts that prevailed till the age of discoveries) the earth appeared in fact as synonymous with the "habitable earth" — the known, three-continental land mass, or *oikoumene* — while the domain of water, or the "Ocean sea", seemed to be as much of an "outer sphere", part of the surrounding cosmos, as it may easily appear to us when we are looking out at the ocean from a deserted beach. Aristotle's cosmos in this sense might be seen as a formidable systematization (and rationalization) of all the animist views that had reigned throughout the ancient world, whose common meaning has been that man confronted the natural universe as something outside himself, or at any rate outside his immediate habitat.

Under this viewpoint, the sequence of the elements seemed to be invariably determined by Aristotle's laws of natural motion, which were in turn founded in ostensible common sense: "Earth" had to be at the center of the cosmic structure, because earth tended to sink to the ground; water (as everyday observation suggested) tended to collect above earth; air rises up and must therefore collect in a sphere above water; fire tends to shoot up towards the sky, and therefore collects in a yet more distant sphere. [12] No matter what logical or empirical problems this order might raise (of which Aristotle was of course aware and which he discussed with his usual perspicuity), the order itself was firmly preordained, so that a person looking out from a deserted beach seemed in fact to be looking at a sequence of "shells" that surrounded him concentrically, before he could see the sky. [13] The orbits of the stars around the earth (which again seemed a matter of common-sense observation) were in fact an extension of this elementary concentric order, so that the geocentric astronomy was in turn inextricably tied to a basic framework of elementary physics, as part of a universal physical cosmology. Anyone wishing to re-think the geocentric system, transposing it into heliocentric terms, would first have to cope with these fundamental

[12] See, *e.g.*, *De generatione et corruptione*, Book II, 3, (330b): "The simple bodies, then, being four in number, make up two pairs belonging to two regions; for Fire and Air form the body which is carried along towards the 'limit', while Earth and Water form the body which is carried along towards the center" (from *Aristotle*, ed. Abraham Edel, Laurel Great Lives and Thought Series, New York, 1967, p. 264).

[13] The problem of how both earth and water could be conceived in terms of these "spheres" is discussed below, in connection with the Medieval debate.

laws of Aristotelian physics and with the earth- or, rather, "land"-centered outlook upon the universe which they implied. However, even before he might tackle that problem, he could conceivably do something else: He could "detach" the innermost core — primarily earth and water — from its context with the cosmic structure and integrate it into one common solid body, thereby placing both the concentric order of the elements and the physical laws which determined that order in doubt — or, in other words, unhinging the whole system, including the concentric orbits of the stars, from its very center. — Which is exactly what Copernicus did. If modern historians like to charge him with an illogical approach (because the revision of Aristotle's laws of motion should have preceded his lifting of the globe from its cosmic context), they seem to be superimposing their modern *ex-post-facto* views upon the actual sequence of the historical process: In actual fact it was Copernicus' freeing of the globe from its ties to the Aristotelian physical cosmos which compelled his successors to carry the critical revision of Aristotle's physics to its ultimate conclusion, after it had gone as far as it presumably could on an essentially abstract level under the hands of fourteenth century scientists.[14] Besides, there were enough novel physical ideas in the Copernican text to stimulate such further investigations.[15]

In order to "lift" the earth out of the Aristotelian cosmos, Copernicus needed an integral concept of the globe in which the element water no longer resided in a separate sphere, but was integrated with the element earth into a compact body. This was in fact what the new geographic evidence permitted him to do. Yet he was undoubtedly aware (as his phrasing occasionally indicates) that the relationship of earth and water had formed the subject of an intense debate, from the thirteenth

[14] In the actual sequence of the historical events it was in fact the recognition of the earth's dual motion which (at least to a significant degree) led to the formulation of the new doctrine of "local motion" by Galileo and others. The connection is stated in elementary terms, *e.g.*, in Herbert Dingle, *Copernicus and the Planets*, in: *A Short History of Science. A Symposium* (based on the BBC Third Programme series), Doubleday Anchor Books, New York, n.d. (originally: 1951), pp. 24 f.; also H. Butterfield, *op. cit.*, ch. 4: "The Downfall of Aristotle and Ptolemy" (*passim*). Cf. note 1 above (esp. Moody's essay) for the essentially abstract treatment of the problem of motion in fourteenth century physics, which would seem to confirm the suggestion that it was Copernicus' theory that shifted the critique of Aristotelian physics to a new level where motion had to be considered as a universal phenomenon, subject to universally valid laws. If it is true (as, *e.g.*, Dingle argues) that motion up to Copernicus was considered exclusively in reference to the earth — towards or away from its center within the "sublunar region", around the earth for the orbits of the stars — so that the phenomenon of motion ("natural" at any rate) was conceived in the same geocentric terms as everything else in the Aristotelian cosmology, it must follow indeed that the concept of the motion of the earth around itself and around the sun disrupted this entire framework and posed the problem of finding an entirely novel set of laws, which had to be developed, first of all, from the observation of free-falling objects, as a logical basis for the formulation of any universal laws. (See also notes 19 and 26 below.)

[15] See below note 26.

century — *i.e.* since the Latin translations from the Arabic had first made Aristotle's scientific writings available to a European public — until the time of the high Renaissance.[16] The problem had stirred up such an amount of public interest that Dante is supposed to have read a paper on the *Quaestio de aqua et terra* before a large audience in Verona in about 1320 (the authenticity of Dante's authorship has been doubted, but the keen interest among the educated fourteenth century public has not); and that two hundred years later Leonardo da Vinci was still entering thoughts about the problem in his *Notebooks.*[17]

The issue of this amazing debate had concerned Aristotle's theory about the sphere of water; more broadly the relationship of the elements water and earth on the globe; and — still more basically — the structure and the ultimate identity of the earthly globe as a whole. With that one might say that the later Middle Ages and the Renaissance had wrestled with the problem of defining the shape and nature of our earthly habitat — perhaps a scientific expression of the same tendencies that led to glimpses of the earthly environment in contemporary literature and art; at any rate an intellectual current that might be considered as a forerunner (or in Leonardo's case an unrelated accompaniment) to the geographic theory of the age of discoveries. The debate had opened with an essential re-statement of Aristotle's views in Sacrobosco's (John of Holywood's) popular treatise on the *Sphere,* early in the thirteenth century: In Aristotle's view, as Sacrobosco summed it up, the

[16] Copernicus repeatedly echoes themes which, while they may go back to Aristotle's ideas, were persistently discussed during the Medieval debate and in fact formed some of its key topics: *e.g.,* the relation of the volume of water to that of earth (*De rev.,* I, 3; see note 21 below); or that "for the safety of living things, stretches of the Earth are left uncovered" (*De rev.,* I, 3); or that the air "contains an admixture of earthy or watery matter" (*De rev.,* I, 8). While the latter idea specifically occurs in the *Meteorology* (cf. note 11 above), speculation on the tendency of water to mix with earth is, *e.g.,* one of the concepts discussed by Robertus Anglicus in his commentary on Sacrobosco's *Sphere* (see note 18 below) and in Oresme's *Livre du ciel et du monde* (cf. note 19). Kuhn has moreover noted a number of basic Copernican ideas which had been anticipated by Oresme (including the theory of optical relativity).

[17] The authenticity of Dante's *Quaestio de aqua et terra* has been doubted, on somewhat farfetched geographic grounds, by Bruno Nardi (but ascribed to an unknown fourteenth century author who supposedly took Dante's name). I propose to deal with the problem more thoroughly in my forthcoming *Terrae Incognitae* article. Leonardo's ideas about the structure of the earth were based on an evident working familiarity with fourteenth and fifteenth century ideas on the subject (from Buridan to Albert of Saxony, Leon Battista Alberti, Nicholas of Cusa), yet seem to have amounted to certain evidently original concepts based on direct observation and subsequent thought, *i.e.,* a "dynamic" relationship between earth and water, determined by the migration of continents across geological time, as well as by the corrosive effects of water on the structure of mountains. He calls water "nature's carter" ("il vetturale della natura") and speculates on a shifting volume of earth and water, due to their mixing, esp. in coastal areas. (See V. P. Zubov, *Leonardo da Vinci,* Engl. translation by D. H. Kraus, Harvard University Press, 1968, pp. 239 f., 241, 230 f., with references to Leonardo's *Notebooks* in their various manuscript editions). It might be noted that Leonardo's entries on these and related astronomical problems seem to have extended through the time when Copernicus began his work on the *Revolutions* (and perhaps until as late as 1518).

problem of conceiving both earth and water in terms of spheric shapes resolved itself by thinking of the element earth as a spherical inner kernel, surrounded by the sphere of water which in turn would be tantamount to the globe. In both instances the perfect sphericity would be marred by the mass of the habitable land, which was conceived as a large-sized "protrusion" from the central kernel of the element earth and which, by the same token, reduced the surface of the sphere of water by about half. [18] (In order to "save" the spheric shape of water despite this substantial reduction of its surface, one would evidently have to assume that the inner kernel of earth was comparatively small, so that one could think of water as occupying most of the interior of the globe.)

Though this would seem an ingenious solution to the problem, it did not satisfy the Medieval mind. A spate of commentators, from the thirteenth century to such leading fourteenth century scientists as Buridan, Albert of Saxony and Nicole Oresme, began to question the Aristotelian concept with remarkable freedom of critical thought. Their critical comments seem largely to have been occasioned by the implicit conflict between the perfection of Aristotle's scheme of spheres and the empirical (*i.e.* geographic) evidence which disturbed that perfection. Re-thinking the scheme, on the slim basis of the available geographic or geophysical facts, they began to question the validity of Aristotle's whole cosmic structure (Oresme, in his *Livre du ciel et du monde,* went so far as to doubt that the elements occupy distinctly identifiable, separate spheres); while another type of comment seemed to anticipate a more compact, less rigidly divided conception of the globe (*e.g.* by proposing that earth and water, according to actual observation, tend to "mix"). However, the entire three hundred year-long discussion (culminating with Leonardo's bold and inspired thoughts) was decidedly hampered not only by a lack of new empirical evidence, but in particular by a pervasive

[18] *The Sphere of Sacrobosco and Its Commentators,* ed. and transl. by L Thorndike, Chicago, 1949, contains significant segments of the debate during the thirteenth century, including Robertus Angelicus' ideas regarding the mixing of earth and water (p. 205; see note 16 above). Sacrobosco definitely identifies the earth with the habitable land "about which is water", thereby perpetuating Aristotle's notorious vagueness concerning the identity of the globe. He projects an unmistakable picture of the sphere of land as inner core from which the three-continental land mass protrudes across the water's surface. Water and the remaining two elements "in turn surround the earth on all sides spherically, except in so far as the dry land stays the sea's tide to protect the life of animal beings. All, too, are mobile except earth which... as a round body, occupies the middle of the sphere" (p. 119). The idea of "mobile" spheres of elements seems to have come from the *Meteorology,* where Aristotle introduces certain "motions" like rising and falling or the mixing of elements; cf., *e.g.,* note 11 above. The idea that the habitable land mass occupies approximately one half — or 180° longitude — of the earth's surface occurs in Ptolemy's *Geography,* which was not explicitly known in the West before 1410. However, any substantial land mass on the surface would evidently have included the same basic requirements.

confusion between the concept of the earth as a whole and of "earth" as an element, synonymous — at least partly — with the known habitable land mass. In the absence of fresh geographic evidence which would have resolved that confusion — and opened up new perspectives upon the whole Aristotelian scheme — this long and amazingly lively debate was therefore confined to a purely speculative level, on which any new and original idea might be as true as again it might not.[19]

While the Medieval and Renaissance debate already reveals a remarkable tendency for revising the Aristotelian cosmology on the basis of facts known about the earth, it is clear that the chief obstacle to any further substantial progress was in the assumption that water constitutes a separate sphere. As long as the known geographic data appeared to confirm this crucial Aristotelian idea — *i.e.* as long as geographic theorists and mapmakers were perpetuating the notion of a two-part division of the globe between the "habitable land" and an impenetrable "Ocean sea" — it was virtually impossible to deny that "outer space" began at the land's edge and from there ascended in a harmoniously ordered succession of spheres towards the orbits of the stars.[20] (It was evidently the

[19] Jean Buridan's and his student Albert of Saxony's pertinent views (from Buridan's *Quaestiones super libris quattuor de caelo et mundo,* ed. E. A. Moody, Cambridge, Mass., 1942; and Albert's *Quaestiones in Aristotelis libros de caelo et mundo,* Pavia, 1481, and his *Acutissime quaestiones super libros de physica ascultatione,* Venice, 1504) are summarized in V. P. Zubov, *op. cit.,* 237 ff. (esp. their distinction between the *centrum magnitudinis* and the *centrum gravitatis* with respect to the earth). N. Oresme, *Le livre du ciel et du monde* (Engl. version ed. A. D. Menut and A. J. Denomy, Madison, Wisc., 1968, p. 569) discusses the distinction between the "geometric center" and the "center of gravity" in terms of the uneven distribution of weight on the earth, in this context touching on the problem of the resp. volume of earth and water; (see note 16 above) and suggesting that the continents are made up of a mixture of earth and water (a point made already by Robertus Anglicus, cf. notes 16 and 18 above). In re-examining the Aristotelian scheme with the help of a diagram (p. 703), ("This seems to be the design Aristotle had in mind", p. 705), Oresme, after some discussion, concludes: "From these arguments, therefore, I conclude and say, first, *that the elements do not have the limited and distinct areas or regions stated above, but that the entire distance between the center of the world* [equivalent to the center of the earth] *and the heavens is indeterminate and indifferent to such division, except that the heaviest element is or tends to be beneath the less heavy*" (p. 707). It might be noted that all Oresme has retained of the Aristotelian laws in this amazing speculation is the basic sequence of the elements, caused by their resp. "volume" or "weight" ("heaviest" against "less heavy"), which determines their — otherwise indeterminate — sites with respect to the "center of the world" (or of the earth, assuming that these two coincide) and therefore their "natural" motion. Consequently, the recognition that the earth moves as a planet — and that therefore its center does not coincide with the center of the universe — opened the way for a more fundamental critique of the Aristotelian system than any of these earlier speculations had permitted, by posing the problem of motion in an entirely new context, *i.e.* outside the earth-centered framework of the Aristotelian cosmology. (See note 14 above; also E. Rosen, "The Debt of Classical Physics to Renaissance Astronomers, particularly Kepler", *Ithaca,* 26 VIII, 2 IX 1962, pp. 81 ff., who already emphasized Copernicus' contribution to early modern physics in this regard, including his new concept of gravity, as resulting from the new astronomical context). See also notes 27 and 28 below.

[20] That the integration of the "sphere of water" with the "sphere of earth" into one solid concept of the globe represented the first and indispensable premise

same notion which caused these vacillations between "earth" as an element, identical with the known land, and earth as the earthly globe. A true concept of the globe, in other words, could only develop once the "Ocean" had been opened up for travel, and therewith integrated with the continents into one continuous entity). It was precisely on this point that Copernicus, in his geographic chapter, introduced the new geographic evidence, concluding that there no longer was any basis for maintaining the idea of a separate water sphere, and asserting that the globe as a whole constitutes a solid body (or, mathematically, a "sphere").

To my knowledge, Copernicus' chapter has never been subjected to a complete analysis of its geographic content. This is admittedly a somewhat difficult task, chiefly because his treatment of geographic problems lacks the kind of synthetizing ability that would have been characteristic of a professional geographer, with the result that his meaning appears at first often rather obscure. It is also difficult to see how the chapter could be understood except in context with that preceding debate, to which Copernicus is quite clearly (although only by implication) referring.[21] The whole point of the chapter is revealed in its heading: "How the Earth, with the Water on It, Forms One Sphere". In the first paragraph he takes up the problem of the relation of water and land on the surface of the globe — the very problem that had preocuppied the Medieval Aristotelians, using virtually the identical phrasing that was so often employed in the Medieval debate: "Thus, for the safety of

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for Copernicus' theory of the earth's dual (esp. its planetary) motion follows from the analysis of his geographic chapter within the context of his heliocentric arguments. (See below, esp. note 25). By the same token, his new physical ideas concerning motion and gravity seem not only predicated upon his separation of the center of the earth from the center of the universe (cf. note 19 above), but again specifically upon the concept of the globe as an integral, solid sphere. (See notes 26–30 below). For significant theoretical anticipations of the new global concept prior to the principal geographic discoveries, see my *Geography in 15th Cent. Florence*. Aristotle's vagueness about the identity of the globe is perpetuated throughout the Medieval debate (including Oresme) and is evidenced by a perpetual tendency of these commentators to confuse "earth" as an element with the terrestrial globe (a confusion which seems in turn to have been perpetuated by their modern English translators).

[21] It seems evident that Copernicus considered the earth as a sphere in geometric terms, after having established its spherical nature on the basis of geographic evidence; cf. below, esp. note 25. This is clearly suggested by his use of the concept "sphere" in the chapters following his geographic discussion, despite his apparent vagueness regarding sphere as a geometrical term without physical substance and a threedimensional body in a different context (see note 6 above). On Copernicus' apparent familiarity with the Medieval debate, see note 16 above. When Copernicus (*De rev.*, I. 3) insists, e.g., that the volume of water must be less than that of earth, he seems to be writing in explicit contradiction to Buridan, Albert of Saxony and Oresme, all of whom had asserted the opposite; V. P. Zubov, *op. cit.*, 237 f.; N. Oresme, *op. cit.*, p. 569. Concerning Copernicus' status as a geographer, I am indebted to Professor Joseph Babicz of the Polish Institute for the History of Science and Technology, of the Polish Academy of Sciences, for his reference to Copernicus' possible share in the map of Prussia; see also E. Rosen, *Three Copernican Treatises*, p. 4 (where the map is attributed solely to Rheticus). I hope to be able to investigate these leads further, in the context of a fuller discussion of Copernicus' attitude towards geography.

living things, stretches of the Earth are left uncovered." [22] But the important difference is that Copernicus here sketches a picture in which the "stretches... left uncovered" no longer refer exclusively to a single coherent three-continental land mass (as they had for the Medieval commentators or on earlier maps), but, in addition, to "numerous islands widely scattered". In fact, he goes on: "Nay, what is a continent, and indeed the whole of the Mainland, but a vast island?" And later on in the chapter, in his reference to the discoveries, he speaks explicitely of "the islands found in our own time under the Princes of Spain and Portugal, particularly America, a land . . . on account of its size, reckoned as another Mainland." In short, the surface of the globe is presented as a continuous alternation of land formations with extended stretches of sea, in which one might think of the continents on the order of "vast islands" and where the continents (or "islands") specifically include the New World.

With this diversified picture of the earth's surface as a starting point, Copernicus proceeds to explode the theory of the sphere of water: If it were true that the globe consists mainly of water — a concept which the idea of a separate water sphere necessarily involves, as we noted above — the land masses would in fact have to be confined to one major, coherent "protrusion" from the inner kernel of earth. The very fact that the surface shows a continuous alternation between land and sea (including "the Mainland of America [which] on account of its position [must] be diametrically opposite to the Ganges basin in India") must mean that the globe consists chiefly of solid matter and that water is essentially limited to the surface, where it "form[s] the seas and fill[s] the lower declivities". [23] Despite his comparative unfamiliarity with the

[22] I hope to be forgiven if for the sake of expediency I am using Kuhn's English translation here (*op. cit.*, pp. 146 ff.). The forthcoming article in *Terrae Incognitae* will include the Latin text, from the Toruń ed.

[23] I have cited Copernicus' text, at least in part, outside of its actual context. (*E.g.*, "The waters spread around the earth form the seas and fill the lower declivities" appears in the opening of the chapter). My purpose (inevitable in an interpretation) was to reconstruct his meaning by singling out his salient thoughts. Since his comparative unfamiliarity with global geographic issues seems to have resulted in a certain lack of organization, so that his ideas are presented in a somewhat rambling and not always logically connected way, it seemed indispensable to try to restore his logic by occasionally disregarding the actual sequence of his arguments. His most direct attack on the idea of the globe as made up mostly of the sphere of water consists in the statement that if the globe were predominantly water, "the depth of the Ocean would constantly increase from the shore outwards, and so neither island nor rock nor anything of the nature of land would be encountered by sailors, how far soever they ventured." While the statement in this phrasing is not necessarily cogent (even if the land mass would be a coherent "protrusion" from a comparatively small inner core of "earth", occasional minor offshoots in the shape of small land formations — and even large formations, in an enormously complex geometric shape — could theoretically still be conceivable), Copernicus is of course substantially correct: The fact of a frequent alternation of sea with land formations, including several unconnected continents, on the surface of the earth would indeed reduce the idea that the interior of the globe consists mostly of water, surrounding a small central core of solid matter, to an extreme im-

handling of global geographic problems, Copernicus has drawn a perfectly logical conclusion from the new geographic evidence concerning the structure of the earth. The old two-partite division of the earth — older than Aristotle, in fact as old as the first known maps — has given way to a "compact" concept of the earth; and the separate sphere of water has been abolished, both on incontestable empirical grounds.

Let me end this paper by expressing my conviction (a) that this new global concept plaid a significant role in the logical development of Copernicus' thinking; (b) that the analysis of this chapter therefore highlights his logic, in handling the non-astronomical premises of his theory, much more convincingly than has been recognized so far; and (c) that his awareness of the far-reaching physical implications of his

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probability (*i.e.*, as long as the land formations are supposed to be connected with that inner core). I think that his next — otherwise virtually unintelligible — sentence must be understood in the same context, *i.e.* as an empirical example in support of this argument ("Yet, we know that between the Egyptian Sea and the Arabian Gulf, well-nigh in the middle of the great land mass, is a passage barely 15 stades wide"). By pointing to the extreme example of the narrow sea passage between the Asian and African continents, west of the Gulf of Aden, "well-nigh in the middle of the great [*i.e.* coherent three-continental] land mass", Copernicus evidently wishes to supply a drastic illustration for the continuous alternating between land and sea formations, and thus to bolster his thesis that water is confined to the surface of the globe. This is followed by the further argument that "modern discovery" (in the Far East) has added an area of as much as 60° in longitude to the 180° extension which Ptolemy had postulated for the habitable world. "Thus we know that the Earth is inhabited to a greater longitude than is left for the Ocean". It is in this context that Copernicus turns to the "islands found in our own time..., particularly America". Though I find it difficult to pin down Copernicus' geographic information which may have led him to this conclusion, it is evident that he is using this presumptive evidence in further support of his main thesis (*i.e.* that the extent of land formations on the surface of the globe precludes — or at any rate severely reduces — the possibility of a globe consisting mainly of water, an argument which is in fact greatly strengthened by the existence of the American continent). Conceivably Copernicus realized that in strict geometrical term the existence of numerous land formations need not absolutely preclude the idea of an essentially water-filled globe, but merely makes it extremely unlikely, and therefore tended to augment his "empirical evidence" regarding the surface area occupied by land. (Geographically, the statement — in effect arguing a two-thirds surface area of continuous land *versus* one third occupied by sea — would seem to presuppose a severely foreshortened idea of the circumference of the globe, presumably the one traditionally attributed to Poseidonius, which was in fact quite commonly accepted in the earlier Renaissance geography; as well as an essential ignorance of the distribution of land and sea in the Southern Hemisphere; and specifically an essential ignorance of the extent of the Pacific; as well as, lastly, an exaggerated idea about the Eastward extension of the Asian continent. I am therefore inclined to conclude that the statement reflects in fact a world map produced prior to the return of Magellan's *Vitoria* in 1522, such as Waldseemueller's of 1507 or Joannes de Stobnicza's of 1512, based on the inset in the Waldseemueller's map, both of which show indeed an Eastward extension of the Asian continent to 240° longitude, which would tend to confirm that Copernicus wrote the chapter around 1512; see note 5 above). The term "modern discovery" with regard to the areas of the Far East may refer to the report of the voyage of N. de Conti; see my *Geography in the 15th Cent. Florence,* pp. 20 f.

For all its occasionally questionable use of geographic evidence, the chapter would seem to show Copernicus as basically accurate in his interpretation of the new geographic data, as they were known by about 1512, for a substantially changed concept of the globe.

basic conception (centered on the new concept of the earth) was far greater than is usually believed.[24] I shall confine myself here to only a few points, leaving a fuller substantiation to another context.

In order to follow his logic, we must above all absolve him of the charge (often made by modern historians) that he was still unduly dependent on many characteristic Aristotelian notions. While granting that the fact itself is true, we ought to see him in his proper historical place, *i. e.* as a pioneer who broke through to profoundly important new insights (including physical), although much of his methodological equipment was indeed obsolete. The true scope of his achievements in this area will not become apparent unless we grant him this, historically inevitable, drawback. However, if we grant him this frame of reference (*i.e.* if we try to follow his reasoning on his own terms), his logic seems to emerge lucidly: Having established the Aristotelian tenet that "Rotation is natural to a sphere and by that very act is its shape expressed" (*De rev.*, I, 4), he proceeds to his decisive conclusion, *i e.* that the earth performs a daily rotation, as well as pursues its own course through the universe as a planet (*De rev.*, I, 5). Even though his explicit arguments in favor of the earth's dual motion are essentially mathematical (in the sense that it offers a more plausible explanation for the apparent daily rotation of the sun and the other planets about the earth, as well as for the observed irregularities of their motions), it seems significant that he does not present this argumentation before having quite elaborately declared the earthly globe as being subject to the Aristotelian "natural circular motion", once it has been defined as a solid sphere on the basis of geographic evidence.[25]

There are, finally, several indications in these opening chapters that Copernicus was aware how much his concept of a solid (and revolving) globe tended to undermine the established system of Aristotelian physics. In Book One, ch. 8, he discusses the "possibility of a double motion of objects" (circular as well as rectilinear), with reference to the motion of water and other elements as well as other objects "so associated with the Earth", in explicit argumentation against the Aristotelian law that only straight up-or-down motion is natural within the "sublunar region".

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[24] See note 3 above for modern criticism of Copernicus regarding these points.

[25] See note 21 above, for his use of the "sphere" as a geometrical concept, after having established its nature as a solid sphere on empirical grounds. The statement "Rotation is natural to a sphere" in chapter 4 follows almost immediately the geographic chapter headed: "How the Earth with the Water on It, Forms One Sphere", thereby indicating a logical progression. The crucial chapter 5, in which he postulates the earth's dual motion, opens — in further logical development of this thought — with the sentence: "Since it has been shown that the Earth is spherical, we now consider whether her motion is conformable to her shape and her position in the Universe." In short, in the logical progression of Copernicus' thought he presents the dual motion of the earth (by applying the traditional Aristotelian tenets) as the direct consequence of the new concept of the earth, resulting from geographic evidence.

Evidently, he had explored the implications of a globe, revolving together with its elements and associated objects, to a point where he could question the Aristotelian laws of motion on these grounds. [26] That Copernicus' new view of the universe in effect eliminated Aristotle's whole "sublunar region", and with that his basis for a dual set of physical laws — one for the sublunar, one for the celestial region — has already been recognized by Edward Rosen, who has pointed out that this opened

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[26] The physical speculation in *De revolutionibus,* (I, 8) is specifically presented in an argument against Aristotle's (and Ptolemy's) physical views, which Copernicus has summarized in I, 7. Though the meaning is, once more, not easy to grasp, I agree with Rosen's general interpretation ("The Debt..."; cf. note 19 above) that Copernicus was aware how much his planetary earth upset the Aristotelian laws of motion, and therefore tended to replace them with his idea of multiple gravity. (See note 28 below). In fact, I interpret the physical speculation in *De rev.,* I, 8 in essence as an intermediary step before he is ready to suggest his new concept of gravity, in *De rev.,* I, 9. As such, his discussion would not be without historical significance: Copernicus is obviously facing the need for an entirely new set of physical laws, once the center of the earth no longer coincides with the center of the universe (see note 19 above). For this new "universal physics" he suggests, however tentatively, that (a) "not only the Earth with the water on it moves thus [*i.e.*, by a dual motion], but also a quantity of air and all things so associated with the Earth" (thereby implicitly establishing the need for a new set of physical laws applying to the earth and its associated elements and objects, since his detaching of the globe from the center of the universe has evidently unhinged all the previously valid laws of motion). (b) Concerning these new laws, he envisages first of all the "possibility" of a "double motion", rectilinear as well as circular — for objects anywhere in the universe, in explicit contradiction to Aristotle who had assigned either one or the other to the "sublunar" or "celestial" region respectively (see note 27 below regarding the disappearance of that distinction). (c) Under these conditions, *i.e.* with the earth moving through the universe, together with its associated elements and objects — it is circular motion which must be uniformly considered as "natural". (*I.e.*, the "natural place and state" for any object — whether within the immediate area of the earth or anywhere else in the universe — is to be "at rest", by moving along a circular orbit). (d) Rectilinear motion, however, "supervenes whenever objects move or are moved from their natural place". Copernicus evidently assumes that the laws of motion determining the fall of heavy objects continue to operate for those objects within the general scope of the earth ("Thus heavy falling objects, being specially earthy, must doubtless retain the nature of the whole to which they belong"). He therewith seems to have singled out the problem of free-falling objects as the one from which the new physics would have to reconstruct its new dynamics (see note 14 above). He has also established the basic premise for his idea of multiple gravity, which he sets forth in the following chapter (see notes 28–30 below).

In a somewhat diffuse and tentative way he has sketched the bare outlines of the new physical universe, which it was now up to early modern physics to fill out or modify: The same laws rule uniformly throughout the universe; circular motion is the basic (or "natural") phenomenon both within the scope of the earth and anywhere else in the universe (for which he supplies at least the seed of an explanation through his concept of gravity); it is "rectilinear" motion which calls for a special explanation, as something occurring when objects "are moved from their natural place"; and, finally, for such "heavy falling objects" he vaguely suggests that their motion has something to do with the nature of the earth "to which they belong". Without wishing to overemphasize the point, it seems to me that the concept of a revolving earth, as a "natural" function of a solid spherical body, is the common denominator behind these various physical notions. It seems to rule Copernicus' vision of a universe in which the circular motion of spheric bodies represents the natural state, and "rectilinear motion" (or free fall) is what now has to be explained.

the way for the early modern system of universal physics.[27] (Putting it differently, one might also say that Copernicus had destroyed the concentric order of the elements — the inner core of the Aristotelian cosmos — by eliminating the separate water sphere and integrating water with the earthly globe.)

Professor Rosen has also called attention to Copernicus' remarkable idea of gravity.[28] Yet again, in Copernicus' phrasing (*De rev.*, I, 9) it is evident that he had developed this concept — however casually he suggests it in this context — from the nature of the earth as a solid sphere and from this basis inferred the existence of the same property for the sun and the planets.[29] Certain striking similarities, in conception and even phrasing, between the Copernican idea and the concept of gravity as later formulated by William Gilbert and Robert Hooke would indicate strongly that Copernicus' solid globe proved a seminal thought for early modern physics even in this crucial respect.[30]

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[27] E. Rosen, "The Debt ...", p. 82. T. S. Kuhn, *op. cit.*, p. 153, very briefly suggests a similar idea.

[28] *Ibid.*

[29] "Now it seems to me gravity is but a natural inclination, bestowed on the parts of bodies by the Creator so as to combine the parts in the form of a sphere and thus contribute to their unity and integrity. And we may believe this property to be present even in the Sun, Moon and Planets, so that thereby they retain their spherical form notwithstanding their various paths."

[30] William Gilbert's experiments with his spherical magnet, "terrella", which enabled him to define the magnetic properties of the earth (and later made it possible for Kepler to extend these properties to the other planets), might be viewed as a significant refinement upon Copernicus' notion that the earth moves according to its spherical nature. Gilbert's suggestion that the earth-magnet possesses the habit of "taking positions in the universe according to the law of the whole" (in his *On the Magnet,* 1600), while it already foreshadows the concept of universal gravitation, seems to reflect Copernicus' vision of the physical universe (see 26 above). Similarly, Robert Hooke in *An Attempt to Prove the Motion of the Earth from Observations* (1674) appears to echo Copernicus' conception (see note 29 above), when he writes: "... all celestial bodies whatsoever have an attraction or gravitating power toward their own centers, whereby they attract not only their own parts, and keep them from flying from them, as we may observe the earth to do" (even though he proceeds from this premise to the decisive step, when he continues: "but... they do also attract all the other celestial bodies that are within the sphere of their activity").