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The age of Plato and Aristotle

INTRODUCTION

The Sophists and the Socratic school dominated the trend of the scientific thought from about the middle of the fifth century to the early fourth century B.C. Our knowledge of this period comes, in general, from the writings of Plato. The Sophists not only thought that the teaching of pure science was degrading but they even attacked it vehemently at times. This condition changed with the advent of Plato who, far from supporting the self-styled 'masters of wisdom' philosophers, professed a great love for mathematics. He was interested in scientific principles and methods – in particular in the elemental structure of the universe. If he had his way, 'there ought to be a law' which would make the study of mathematics compulsory to all would-be statesmen. Inscribed across the top of his academy was the statement: 'Nobody should enter who is not a mathematician'.[1]

No man had ever influenced the development of scientific thought for such a long time as had Aristotle, and it is highly unlikely that his record will ever be exceeded. His opinions had withstood the test of time for nearly two millenniums. Admittedly it had some ups and downs during this period but it is still a remarkable achievement. Aristotle was an encyclopaedist, and with the probable exception of Democritus, he was the first encyclopaedist of the human race. Much of our scanty knowledge of the Greek philosophy is handed down to us from his writings. He was a disciple of Plato but he far surpassed his master in every branch of knowledge. This was true to such an extent, that some claim Plato became well known largely because he was the teacher of Aristotle. Plato's contribution to knowledge was in the form of imaginary conversations between persons. It is often impossible to distinguish historical facts from pure fiction, therein. Aristotle's approach was entirely different. He almost invariably assembled the opinions of learned men of bygone days and then added his own contributions to them.

In this chapter Plato's and Aristotle's contributions to the development of the science of hydrology will be briefly examined.

PLATO

His life

According to Alexandrian scholars, Plato (figure 1) was born in the month of *Thargelion* (May-June) of the first year of the eighty-eighth Olympiad (498–427 B.C.). Son of distinguished Athenian parents of the Periclean era, Ariston and Pericrione, he devoted most of his life to the search for truth. It is highly probable that even as a boy, he knew Socrates and his early ambition appears to have been political. The execution of Socrates in 399 B.C. on a trumped up charge of impiety affected him profoundly, and it probably made him give up his political aspirations. He visited Italy and Sicily, and in about 387 B.C., on his return to Athens, he founded the Academy, an event which was a mile milestone in the history of science and philosophy.

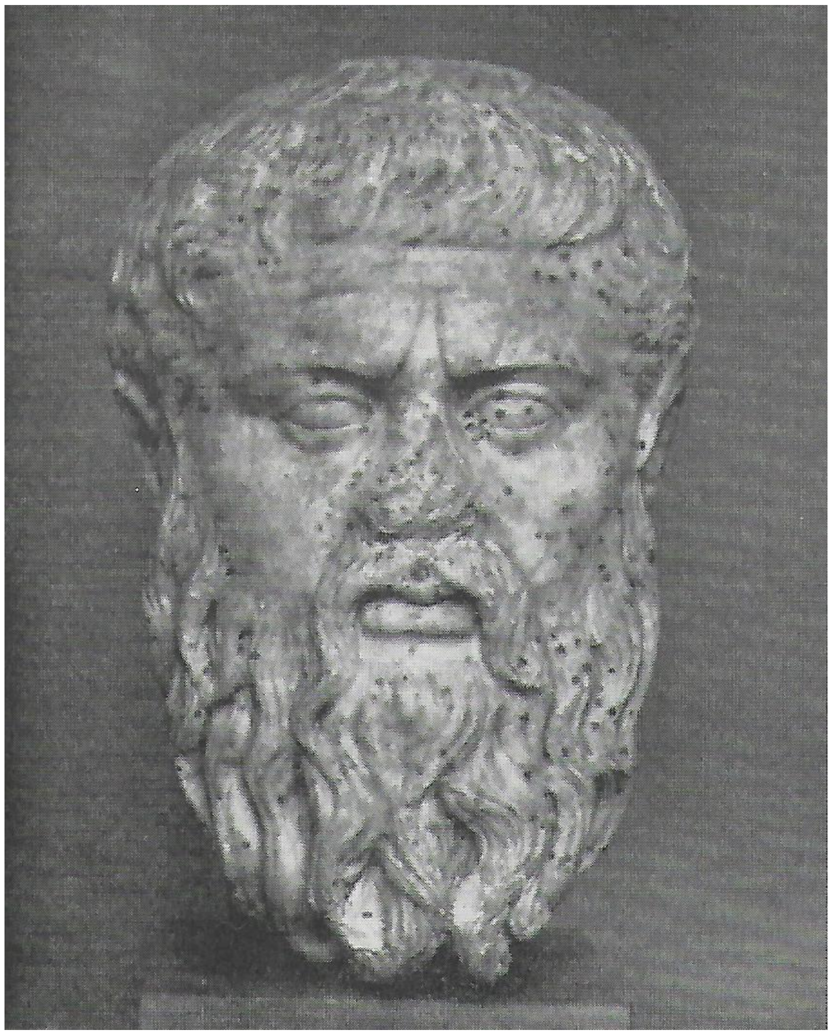

Figure 1. Plato (by courtesy of Ny Carlsberg Glyptotek, Copenhagen).

He was invited to educate the new 30-year old King Dionysius II of Syracuse in 367 B.C. Finding that he was not very successful at that task, he returned after a few months to Athens. King Dionysius again persuaded Plato to continue that effort in 361 B.C., but in this second attempt he again failed to induce the King to follow a course of combining both power and philosophy. Within about a year he returned to Athens (at a considerable personal danger) and from then on he never again ventured into politics. He spent the remaining years of his life at the Academy and died in 348 or 347 B.C.

Water – a primary element

Plato accepted the concept of the four basic elements of matter, fire, air, water, and earth, as first postulated by the Greek philosopher Empedocles of Agrigentum, but added thereto a fifth element which he describes in somewhat mysterious terms.[2] Aristotle later explained that the fifth element must have been heaven. Proclus in his commentaries quoted Plato's *Timaeus* as saying that 'He who constituted the world composed it from all fire, air and earth, leaving no part nor power of any one of them externally'. Then he adds:

> 'He does not say from fire or water simply, but from all fire and all water, through which he indicates that there is much fire in the universe, and of a different nature, and also much water, and which is essentially different. Moreover, the theology of the Assyrians which was unfolded into light from divinity, delivers the same things. For in that theology, the Demiurgus is said to have made the whole world from fire, water, earth, and all-nourishing ether or air; and the artificer is said to have fashioned the world as it were with his own hands.'[3]

The four *archē* theory accordingly does not seem to have been new – Empedocles apparently borrowed it from the Assyrians.

Plato's main scientific work is considered to be *Timaeus*, which, according to Sarton, has been considered by many commentators as the ultimate of Platonic wisdom which prevailed for the thousands of years thereafter, but which 'modern men of science can only regard as a monument of unwisdom and recklessness'.[4] *Timaeus* is of some importance to hydrologists because it attempts to describe a mathematical theory regarding water – one of the five basic elements of the universe. His thought was that 'as the world must be solid, and solid bodies are always compacted not by one mean but by two, God placed water and air in the mean between fire and earth and made them to have same proportion so far as was possible (as fire is to air so is air to water, and as air is to water so is water to earth) ... out of such elements which are in number four, the body of the world was created, and it was harmonized by proportion, and therefore has the spirit of friendship.[5]

The Athenian mathematician Theaetetos was the first to formulate the theory of polyhedra – often known as Platonic bodies. Since he is the principal character in one of the most famous of Plato's dialogues it is not unreasonable to believe that Plato obtained his concept of five regular solid figures from Theaetetos. The theory of polyhedra stated that there could only be five regular solid figures having as their sides regular identical polygons and without any re-entrant angles. Plato assigned four of the five polyhedra to the four Empedoclean elements. The remaining fifth compound figure was referred to in the following somewhat mysterious terms: 'There was yet a fifth combination which God used in the delineation of the universe'.[6] Thus air consisted of octahedra, water of icosahedra, fire of tetrahedra, earth of cubes, and heaven (?) of dodecahedra (figure 2).[7] The reason for assigning icosahedra to water was because the form was least mobile and had the greatest body.

The Polish logician Wincenty Lutowslawski made a remarkable comment in his book on the *Origin and growth of Plato's logic*. He believed that from Plato's writings one can conclude that[8] water consists of three atoms: two of one gas and one of another – which undoubtedly is stretching the cult of Plato too far. Sarton comments: 'Lutowslawski reminds me of the people who read scientific anticipations of the Bible or the Qur'an'.[4]

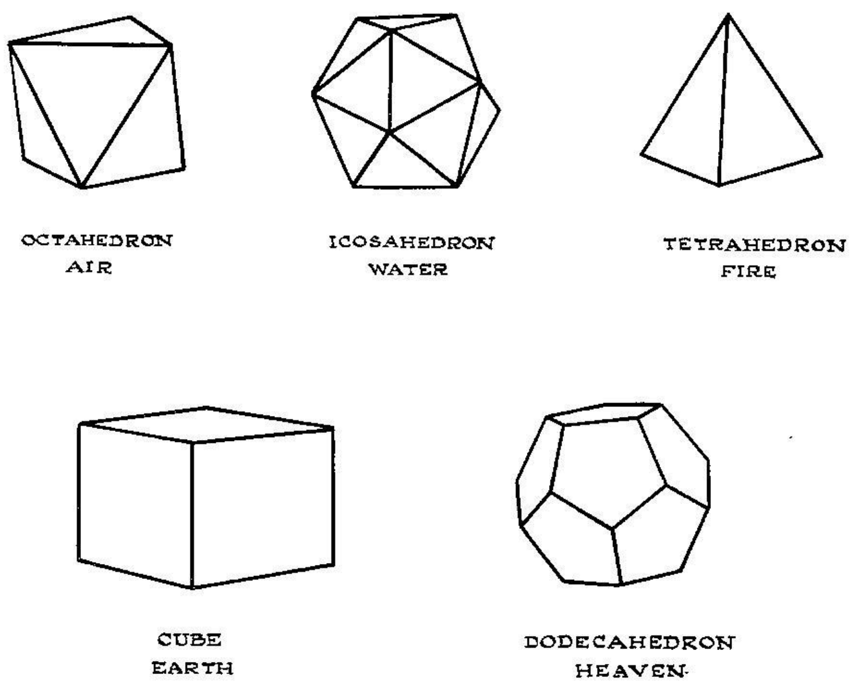

Figure 2. Platonian concept of elements.

Origin of rivers and springs

Two possible explanations are available in the dialogues of Plato on the origin of rivers and springs, of which the most quoted hypothesis[9] is the Homeric ocean (Tartarus) concept. Plato believed that there are numerous interconnected perforations and passages, broad and narrow, in the interior of the earth.[10] He imagined the existence of a huge subterranean reservoir called Tartarus. This was the vastest of all chasms, and it penetrated the entire earth. The watery element therein had neither a bed nor a bottom; it always surged to and fro. 'When' Plato wrote, 'the water retires with a rush into the inner parts of the earth, as they are called, it flows through the earth into those regions, and fills them up like water raised by a pump. When it leaves those regions, and rushes back hither, it again flows into the nearby hollows, and when these are filled, it flows through subterranean channels and finds its way to several places, forming seas, and lakes, and rivers, and springs'.[10]

All waters of rivers and streams flow back to Tartarus directly or through a circuitous route. Like the Egyptians, Plato was aware of one of the fundamental principles of water, that it always flows downhill. Perhaps that was why he stated that the entrance of the rivers back to the earth was always lower than the level at which they originated. The flow from Tartarus to the rivers and vice versa was a continuous process.

The alternate possible explanation of the origin of springs and rivers can be found in *Critias*. Speaking of conditions at Athens some 9000 years before his time, Plato said:

'Furthermore it [the land of Attica in ancient times] enjoyed the fructifying rainfall sent year by year from Zeus; and this was not lost to it by flowing off into the sea, as nowadays because of the denuded nature of the land. The land [then] had great depth of soil and gathered the water into itself and stored it up in the soil we now use for pottery clay, as though it were a sort of natural water-jar; it drew down into the natural hollow the water which it had absorbed from the high ground and so afforded in all districts of the country liberal sources of springs and rivers; and surviving evidence of the truth of this statement is afforded by the still extant shrines, built in spaces where springs did formerly exist.'[11]

The Tartarus concept gives an account of the origin of streams and rivers, and a question arises as to whether it represents Plato's own view or someone else's. Krynine, for example, regarded the Platonic idea of a huge subterranean reservoir as 'an ironical one' on the basis of a statement of Socrates to one of the principal characters of the dialogue *Phaedo*, that 'I can tell you a charming tale, Simmias, which is well worth hearing'.[12] He went on to credit Plato with describing the first pluvial concept of the hydrologic cycle. Krynine then stated that the 'origin of springs and rivers [as] postulated in the *Critias* is based on acute observation and not on a tongue-in-check embellishment of Homeric myths as in the *Phaedo*'. [12]

It is true that Plato describes the other world (including Tartarus) in its relationship with the immortality of the soul. 'He does this without pretending that his account is exact, but this he says, or something like this, must be true. His picture of the other world is borrowed partly from the mythological tales of the poets and the priests, partly from the physical speculations of the philosophers, and is in a good measure, as we can perceive, expanded and adorned by Plato's own imagination'.[13] Thus, his account was partly mythological and partly literal, and it is almost impossible to distinguish one from the other as the transition has been entirely disregarded. Perhaps Taylor has the last word: 'It is useless to discuss the question how much in these myths of the unseen represents a genuine extra belief of either Socrates or Plato, and how much is conscious 'symbolism'. Probably neither philosopher could have answered the question himself'.[14]

It should be pointed out however, that Aristotle takes Plato to task[15] because of his acceptance of the Tartarus concept of the origin of springs and rivers, without ever having mentioned the pluvial concept as having been previously describes in *Critias*. It is difficult to believe that Aristotle could have made such a critical statement unless he was convinced of Plato's belief in the Tartarus idea,[16] despite of the fact that the Stagirite was a very unsympathetic critic of his master.

The passage quoted by Krynine in support of his claim that Plato was the originator of the pluvial concept, is from the Bury translation,[17] but it is extremely difficult to draw the same conclusion from other major translations like the Jowett[18] or the Taylor[19] (the one used in this chapter is a literal translation). The passage concerned is extremely involved, and there are reasons to believe that some of it is corrupt.[20]

Krynine discards the Tartarus idea as parageological, Dantesque, and a 'charming tale', but such a criticism is not valid. In the beginning of his speech *Critias* invoked the aid of all the Gods, especially Mnemosyne (the Goddess of Memory), because he had heard the 'tale' he was about to narrate from Solon of Athens (635–558 B.C.), one of the seven wise men, who in turn had heard it from an exceedingly old Egyptian priest. Thus if Tartarus is to be discarded as a 'charming tale', then the 'tale' of the pluvial concept should also be discarded on the basis of the same reasoning (assuming that Plato did in fact propose such as hypothesis). Besides the whole story 'has so much the appearance of a myth, that it seems useless to apply to it any of the laws of historical or geographical criticism'.[20]

Rivaud believed that much of the denudation of Attica, ascribed by Plato to the natural cataclysm, was actually the work of man.[21]

He also pointed out that the tale of the lost island of Atlantis came from Egyptian priests, and as they took great pleasure in deceiving the Greeks, that tale is not surprising. But nowhere does he suspect that 'there is a greater deceiver or a magician than the Egyptian priests, that is to say, Plato himself, from the dominion of whose genius the critic and natural philosophers of modern times are not wholly emancipated'.[22]

Finally, 'Atlantis is a creation of Plato's own imagination – a creation which he knows how to give versimilitude to by connection with the accepted 'scientific' doctrine of terrestrial catastrophies'.[23]

Thus, the reader of the *Critias* must bear in mind that 'the geology of that work is, after all, the geology of the Aetiological Myth, in which a result, which Plato, as scientific observer, may well have conceived as due to a secular process, was bound to be attributed to a 'catastrophie'.[23] Sarton comments: 'Many geologists have wasted their time in trying to give some appearance of reality to Plato's dream'[22] but whatever may be the merits or the demerits of the dialogue *Critias*, it does indicate that Plato did take some interest in the observation of natural processes.[24]

Thus, it is concluded that it is futile to disregard the Tartarus theory of Plato and credit him with only the pluvial concept of the origin of springs and rivers, as suggested by Krynine. He should be credited with both; assuming that he did put forward a second hypothesis.

Water laws

Plato was interested in water laws and his ideas will be briefly discussed herein. In general, he was satisfied with the old laws, and did not see any good reason for changing them.

Anyone was permitted to draw water from a common stream on his land as long as he did not cut off the flow of a private stream. The water could be caused to flow in any direction except through a house, temple, or sepulchre, but one needed to be careful not to do any harm in excess to the excavation of the channel. In case of water deficiency, one should dig down to the clay layer, and if still no water was found, he had the right to obtain water for his household from his neighbour. If his neighbour's supply was limited, he was permitted to obtain from him an amount as determined by a warden.[25] A man living on higher ground was not permitted to allow the runoff resulting from a heavy rain to drain recklessly on or could the lower neighbour to the land of his lower neighbour, refuse to furnish an outlet for reasonable drainage from the higher land. In case of dispute the warden would decide what would be required of each man. If any one intentionally polluted or wasted the water of a stream or reservoir of another by poisoning, digging, or by theft, he would be required to pay damages equal to the value of the loss. If he had polluted the water, he also had to purify the water. If the previous Platonic concept had been followed continuously throughout the ages there would have been no water pollution problems for us to contend with at present!

ARISTOTLE

His life

Aristotle (figure 3) was born in 385 B.C. in the city of Stagira in Macedonia. His father, Nicomachus, was a celebrated physician at the court of Amyntas III[26] (the father of Philip of Macedon). He entered Plato's Academy in 367 B.C., and left (some 20 years later) after the death of his teacher. At the invitation of King Philip, Aristotle became tutor to the young prince Alexander. About seven years were devoted to teaching Alexander politics and rhetoric. After the accession of Alexander, Aristotle returned to Athens, where, because Xenocrates denied him the headship of the Academy, he founded the Lycaeum, later renowned as the Peripatetic School, which was an immediate success. Like Plato, he was interested in knowledge for its own sake. After the death of Alexander a revolt took place in Athens, and he was threatened with false prosecution. Remembering the fate of another great philosopher, Socrates, he promptly fled to Chalcis and died there after a few months in 322 B.C.

Concept of water

The Aristotelian concept of the universe is somewhat similar to that of Pythagoras and Plato. He believed in five elements and each element was credited with two of the following four qualities: cold, hot, dry, and humid. Four 'earthly' elements thus had four qualities cold-dry (earth), cold-humid (water), hot-dry (fire), and hot-humid (air). They could engender each in a circular way (figure 4), and he quoted Empedocles in support of his theory:

'The sun everywhere bright to see, and hot;
The rain everywhere dark and cold.'[27]

Figure 3. Aristotle (by courtesy of National Museum, Naples).

Aristotle's universe was unique and finite. Each element had its appropriate place in the universe, and its nature was to move toward such a place. Having reached there, it would cease to move any further. He believed the earth was at the centre of the universe, and that it was surrounded by water, whereas fire was below heaven but above air. Nothing existed beyond the highest heaven – not even a surrounding void, because space was finite.[28] Figure 5 is a medieval representation of the elements of the earth according to Aristotle.[28]

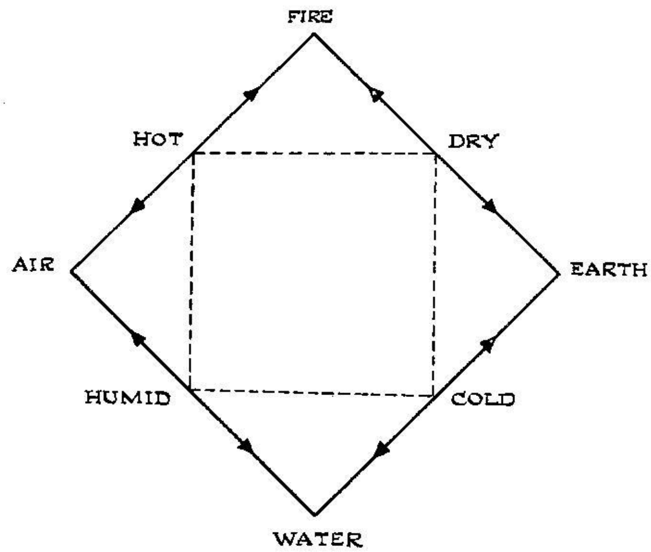

Figure 4. Aristotelian concept of elements.

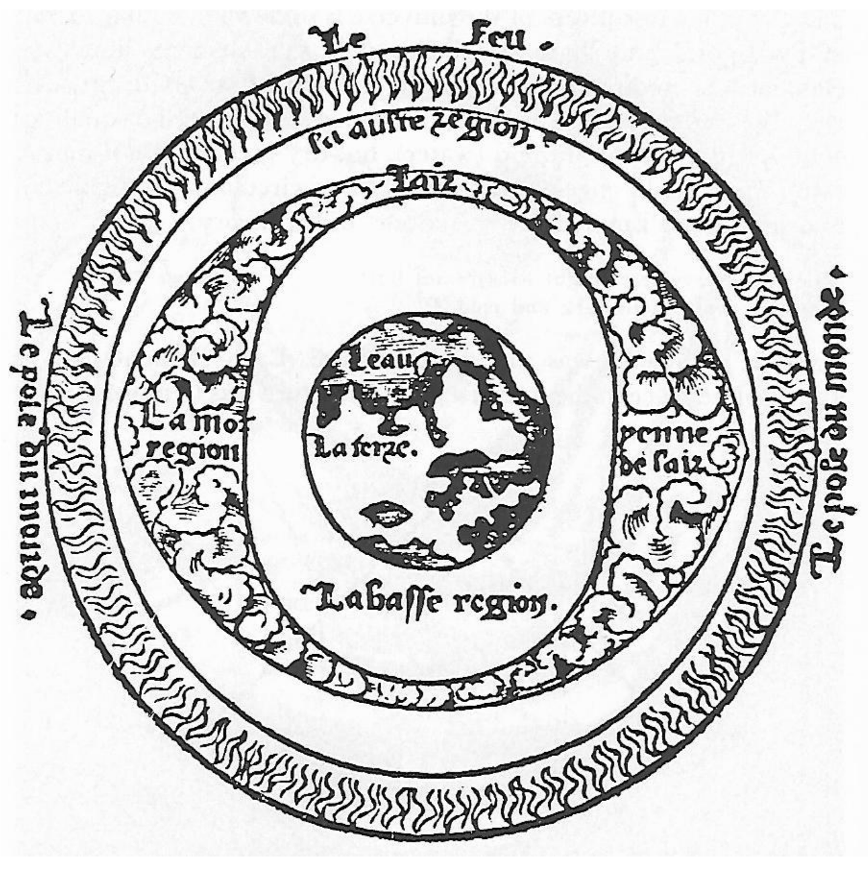

Figure 5. Position of elements according to Aristotle (from Fine, *La théorie des ciels, mouvements, et termes pratiques des sept planèts*, 1528*).*

First book on meteorology

Aristotle was the first man to write a treatise on meteorology. It was entitled *Meteorologica*. Not only did it deal with meteorology, using the root of the modern word, but also with astronomy, chemistry, geology, and physics. It is quite likely that the fourth book of *Meteorologica* was written by Straton,[29] and it may be considered to be the first elementary text on chemistry to have been written.

However, the portions of the book most likely to interest the hydrologists deal with rain, dew, hail, snow, wind, ocean, and the origin of rivers and springs.

Mechanics of precipitation

Aristotle, like his predecessors, did not have a clear concept of the difference between air and vapour. Air, he said, being hot and moist, is a sort of aqueous vapour. He believed that two types of evaporation took place from the earth's surface due to the sun's heat: one was evaporation, and the other was a kind of windy exhalation which was like smoke, but which arose from the dry earth. The windy exhalations being drier and warmer, would rise above the moist vapour. Aristotle argued that as the sun approached or receded from a place, it gave rise to the dissipation or condensation of vapour, which were forms of degeneration and destruction. He believed that the heat responsible for evaporation came from the sun and also from the 'other heat from above',[29] but he did not explain his second source.

The water vapour gradually loses heat as it rises, partly due to its rising far into the upper air, and partly due to dispersion into the higher region, with the result that it condenses and changes from 'air into water'.[30] The condensed 'air' thus forms clouds which in turn produces rain. Mist is formed from what is left over after the cloud has been turned into water. In other words, mist is a form of 'barren cloud', and hence is a symbol of good weather rather than of rainfall. As the sun approaches a particular locality, evaporation takes place, and as it recedes, condensation and rainfall occur – thus forming a cyclical process which follows the course of the sun. Then followed what was no doubt Aristotle's conception of what we call the hydrologic cycle:

> 'Some of the vapour that is formed by day does not rise high because the ratio of the fire that is raising it to the water that is being raised is small. When this cools and descends at night, it is called dew and hoar-frost. When the vapour is frozen before it has condensed to water again it is hoar-frost ... It is dew when the vapour has condensed into water and the heat is not so great as to dry up the moisture that has been raised, nor the cold sufficient (owing to the warmth of the climate or season) for the vapour itself to freeze.'[31]

Rainfall results from the condensation of a great amount of vapour from a considerable area over a long period of time, whereas dew is produced from the vapour collected in a single day from a small area as indicated by its quick formation and scanty quantity. The freezing of cloud produces snow. Hoar-frost occurs as the product of frozen vapour. The relationships between rain and dew, and snow and hoar-frost are accordingly similar; that is, there is a great deal needed to produce the former, and very little to produce the latter.

Aristotle believed that the intensity of rainfall was directly dependent on the rate of condensation of water vapour, and that heavy showers would occur as a cloud descended into warm air. This was exactly opposite from the view expressed by Anaxagoras.

Origin of springs and rivers

Aristotle was critical of Anaxagoras' concept of the origin of rivers. Anaxagoras had envisaged a subterranean reservoir or reservoirs from which all rivers originated, and that such rivers were perennial if the reservoirs in question could store enough water to last until the arrival of the winter rains. Without adequate storage, the rivers just dried up for some periods during the year. Aristotle, to the contrary, contended that if a single reservoir existed which was capable of storing all the water flowing in the rivers continuously day by day, its size would have to be larger than the earth itself, or under most circumstances, not much smaller.[32]

Having thus disposed the Anaxagorean theory, Aristotle derided the concept of Tartarus as propounded by his teacher Plato. He argued first, that if that theory were correct, rivers would flow in a direction which conformed with the surging of Tartarus, and that this direction was not necessarily downwards in all instances. The proverbial case of a river flowing upward could then become reality; second that the Tartarus theory does not take into account generation of new water – that if all the water that flowing out of Tartarus goes back there again, how can the loss of water due to vaporization be accounted for? The treatise gives the impression that Aristotle was very surprised to find that one could be stupid enough to make the mistake of neglecting the formation of new water. His final argument was that none of the rivers on or in the earth go back to Tartarus but that they in fact discharge either into the sea or into one another. He thereupon concluded that all these factors make the Platonic concept of a huge subterranean reservoir clearly impossible, particularly so, because the theory about the subterranean sea was supposed to have originated from Tartarus. Having thus discarded Anaxagorean and Platonic postulates, Aristotle went on to submit his own views on the subject. He said that if cold changes air into water above the earth, it must also produce the same effect within the earth. Thus there is continuous conversion of air into water inside of the earth, and it would be extremely unreasonable for anyone to refuse to admit it.

'Just as above the earth, small drops form and these join others, till finally water descends in a body as rain, so too we must suppose that in the earth the water at first trickles together little by little and that the sources of rivers drip, as it were, out of the earth and then unite. This is proved by facts. When men construct an aqueduct they collect water in pipes and trenches, as if the earth in the higher ground was sweating the water out. Hence, too, the headwaters of rivers are found to flow from mountains, and from the greatest mountains there flow the most numerous and greatest rivers. Again, most springs are in the neighbourhood of mountains and of high ground, whereas if we except rivers, water rarely appears in the plains. For mountains and high ground, suspended over the country like a saturated sponge, make the water ooze out and trickle together in minute quantities but in many places. They also receive a great deal of water falling as rain.'[33]

Another explanation for the origin of rivers and springs is given by Aristotle in the continuation of the passage quoted above, viz.: 'they *also* cool the vapour that *rises* [the author's italics] 'and condense it back into water'.[34] The passage is rather obscure and, according to Kircher,[35] there was considerable controversy in the middles ages about the origin of the vapour that rises, as nowhere in his treatise did Aristotle mention where it came from.

Thus Aristotle had three different explanations for the origin of rivers:

(1) rainfall and percolation;
(2) subterranean condensation of 'air' into water; and
(3) condensation of vapours rising (from some source not stated).

He held that the mountains act as spongy receptacles. If these reasons, single or in combination, truly explain the origin, what would make the river perennial or seasonal? Aristotle was ready with his answer. In brief, the reason which he gave lies in the size of the mountains and their density and cold temperatures. He contended that if mountains are big, dense, and cold, they can catch, create, and retain most of that water, and hence the rivers which originate within them will be perennial. If on the contrary, they are small, or porous and stony and clayey, they will soon lose their supply of water, and the resulting rivers will consequently have only seasonal flow.[36]

Saltness of the sea

Aristotle, like Hippocrates, believed that only the lighter and the sweeter portions of water were evaporated by the sun. He argued that the sea must persist forever because as the sun approaches water, it is drawn up, and as the sun recedes, the water comes down as rain. As long as this arrangement continues the sea should never dry up.[37]

When the water of the sea evaporates, it somehow rids itself of its salty taste. He could vouch for that from the experiments he conducted.[38] This phenomenon, he declared, is true of all wines and fluids. When distilled, they become water.[39] His explanation for the salinity of sea-water was strange indeed, however, because he believed that such salinity was due to the earthy residue always left by everything that grows and is naturally generated in this world. Since moist and dry evaporations are mixed, some quantity of it must exist in the clouds, and hence when precipitation occurs, it carries with it the saline dry exhalation. This reason was also given for the salinity of the first autumnal rains and rains coming from the south. As this process is repeated continuously the sea gradually became salty.

CONCLUSION

Plato's major contribution to hydrology was the two hypotheses he put forward for the origin of rivers and springs. Of the two, the Tartarus concept has been the most quoted one, and Plato was severely criticized for it by Aristotle. It appears that Plato had also put forward the pluvial concept in his work *Critias* which has received very little attention so far. It is suggested that Plato should be credited with both the Tartarus and pluvial hypotheses on the origin of rivers and springs.

It is extremely doubtful if any one could successfully argue against the fact that Aristotle was one of the greatest intellects of all time.[40] His interests had an encyclopaedic range, and he had grasped the principles of scientific method more than any other man before and long after his time. His approach to knowledge was rather pedantic, and his greatest contributions were in the field of biology. The Aristotelian School collected a large number of observations from which they derived many intelligent interpretations, but often they were wordy and inconclusive. Sometimes he finished his explanations with the words *kai para tauta uden* (and beyond that nothing else). He did pass along some old-wive's tales such as men have more teeth than women, and although he had been twice married, it apparently never occurred to him to check the truth of that tale by making observations. It may be said that the Greek did not have a knowledge of measuring instruments, and hence should be excused for resorting to speculations, but this condonation would be all too generous.[41] Undoubtedly they were capable of measuring length (linear straightedge), time (water-clock), and weight (balance), but they did not make any general use of them. They were more interested in 'why?' than 'how much?' Aristotle stated that 'All men by nature desire to know' but mankind had to wait for nearly another two millenniums for Johann Kepler to add 'to *measure* is to know'.

Perhaps the contributions of Plato and Aristotle to the science of hydrology can be best summed up by the words of Aristotle which are engraved in the National Academy of Sciences Building in Washington, D.C.:

> 'Search for truth is one way hard and in other way easy, for it is evident that no one can master it fully nor miss it wholly, but each adds a little to our knowledge of nature, and from all the facts assembled there arises a certain grandeur.'

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