Leonardo da Vinci--Pioneer Geologist

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Introduction

The fame of Leonardo da Vinci as one of the greatest minds of the Renaissance, indeed of all time, is well known to scholars in many fields; artists are familiar with his painting and sculpture, architects, and engineers have marveled at his designs for churches, basilicas, etc., and students of mechanical, aeronautical, and civil engineering are familiar with his many inventions and mechanical devices including the airplane, helicopter, parachute, screw propeller, lathe, drill press, pile-driver, and many others; students of medicine and anatomy have studied carefully his anatomical drawings and notes, and realize his many contributions to our knowledge of the human body.

His brilliant contributions to the science of geology are less well known, however, although they are contained in his many notebooks, in a great profusion of observations, measurements, and brilliant deductions concerning such diverse subjects as the origin of fossils, the true nature of sedimentary rocks containing marine organisms, the laws of hydrology, the origin of sediments, and the nature of internal earth forces.

It is therefore the purpose of the present writer to call the attention of earth scientists to a few of the many concepts and principles of geology which were first described by Da Vinci.

Brief Biography of Da Vinci

In order to understand the background of Leonardo's intense interest in the earth and its processes, one must be aware of some essentials of Leonardo's life story. He was born in the village of Vinci, near Florence, in 1452 and was apprenticed in his school years to the painter Verocchio. After seven years of training, he began his own career in painting. In the early 1480's, he entered the service of the Duke of Milan, whom he served as court painter, architect, military adviser,

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and engineer. When the French seized Milan, Da Vinci returned to Florence, where he resumed his painting and sculpture. He later returned to serve the French king as military engineer, architect, and court painter. Following another sojourn in Florence and in Rome, where he joined Raphael and Michaelangelo in a reconstruction of St. Peter's church and the Vatican, he again returned to France at the invitation of Francis I. The French monarch was so pleased with Leonardo and his many talents that he gave him a chateau near Ambois, where Leonardo lived until his death in 1519.

It was during his service in the court at Milan, while devising canals, dams, and fortifications along the River Arno and its tributaries, that his intense interest in hydrology, sedimentation, and geology grew and flourished. His appreciation of terrain from both an engineering and a military point of view led him to the intensive observations and studies which constitute much of his writings on geology.

The Da Vinci Manuscripts

During his long and active career, DaVinci wrote prolifically in a series of notebooks, miscellaneous manuscripts, and letters, which were returned to a friend in Milan, who during his lifetime guarded them as relics. However, on the death of Da Vinci's friend, they soon became scattered. In subsequent years two collections were assembled by donation and purchase: one at the Ambrosiana Library in Milan, the other at the Institute de France, in Paris, where they now rest. Other manuscripts are in the British Museum, Windsor Castle, the South Kensington Library of Art and Science, Holkham Hall, and the treatise on painting rests in the Vatican Library in Rome.

While Da Vinci's fame as painter and sculptor spread over the world during his life and after his death, his contributions to science remained hidden because of the apparent illegibility and undecipherable nature of his writings.

Thanks, however, to the painstaking work of the German scholars Richter and Müller-Walde, who patiently deciphered the so-called "mirror writing" of the master's manuscripts (Da Vinci actually wrote backwards for secrecy's sake), and to the British scholar Edward MacCurdy, the wealth of Da Vinci's scientific discoveries, his inventive genius, and his almost uncanny grasp of the function of the natural world around him is now available for all to read and to ponder with amazement—a rich treasure of observations, experiments, deductions, and conclusions which establish Leonardo da Vinci as one of the great scientific geniuses of the world.

In 1952, on the 500th anniversary of the birth of Da Vinci, scientists from many parts of the world gathered at Illinois Southern University to acclaim his genius, and to honor him for his discoveries in virtually all the sciences. At this historic meeting, Hadley (1952) of Illinois Southern University said:

> The ordinary person remembers Leonardo chiefly as an artist and hardly thinks of him as a forerunner of our scientific age. He may have lived by the brush, but his first love was scientific research, and he preferred to be known as an inventor.
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> Prior to Leonardo, most of the experimenters were alchemists and these had degenerated into mere hunters for a way to transmute lead into gold.
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> He kept his discoveries to himself by his mirror script, hence he did not suffer the fate of many pioneers. It has been left for recent generations to pay him tardy tribute and justice as an inventor, as the originator of the scientific method.

It is from the English translation of Da Vinci's notebooks, published in 1939 by Edward MacCurdy, and arranged by subject, that the present writer has selected those passages which reveal the pioneering researches which entitle Leonardo to be called the "Father of modern geology."

This paper will consider the writings of Leonardo da Vinci on the specific subjects of fossils, processes of sedimentation, stream erosion and the history of valleys, and on internal earth forces, notably the principle of isostasy, or adjustment between continents and ocean basins.

Da Vinci on the Nature of Fossils

As in many of the branches of natural science which commanded his attention, Da Vinci rediscovered or restated many of the observations and concepts of the Greek natural historians, including Aristotle, Theophrastus, and Xenophanes.

This is particularly true of his writing on the nature of fossils. Xenophanes (540 B.C.) noted that sea shells found in and on the sides of mountains were proof that the sea can dissolve earth when they mix. Aristotle had seen fossil fishes in rocks of many localities, but he assumed that they lived there; his pupil Anaximander assumed that these strange objects grew in the rocks from eggs left by fishes which had travelled long distances from the sea. Strabo (7 B.C.) wrote that the elevation of the land by internal fires had caused mountains to rise out of the sea, hence the reason for shells being present on the sides of mountains.

Since it was the authoritative writings of Aristotle on science and the natural world which became frozen into the dogma of the medieval Christian Church, no true idea of the origin and nature of fossils was preserved in ecclesiatical dogma. In the Middle Ages, several interesting concepts were extant concerning the nature of fossils, for they were treated as individual loose rocks, or stones, and not as a part of the masses of lithified rock from which they had been weathered out. Some believed that these odd-shaped stones, such as shark's teeth, fossil corals, belemnites, etc., were formed in place by heavenly powers and were endowed with magical powers. These were grouped together with odd-shaped pebbles, geodes, concretions, and mineral crystals, and were sought for their supposedly curative powers, or for their magic in warding off spells, evil spirits, etc. Some writers even believed that piles of fossils in layers were imperfect results of the attempt of the Divine Creator to make man.

At the close of the Middle Ages and the beginning of the Renaissance in Italy, the majority of scholars recognized the similarity of the fossil shells to modern forms, but sought to explain their presence in layers on the sides of the mountains of Italy as vestiges of the great Noachian Deluge.

In 1508, Da Vinci wrote the following concerning the Deluge concept of the origin of these peculiar remains:

> Of the bones of fishes found in those that have been petrified:
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> All the creatures that have their bones within their skin, on being covered over by the mud from the inundation of rivers which have left their accustomed beds, and are at once enclosed in a mould by this mud. And so in the course of time as the channels of the rivers become lower these creatures being embedded and shut in within the mud, and the flesh and organs being worn away and only the bones

> remaining, and even these having lost their natural order or arrangement, they have fallen down into the base of the mould which has been formed by their impress, and as the mud becomes lifted up above the level of the stream the mud runs away so that it dries and becomes first a sticky paste and then changes into stone, enclosing whatsoever it finds within itself, and itself filling up every cavity; and finding the hollow part of the mould formed by these creatures it percolates gradually through the tiny crevices in the earth through which the air that is within escapes away—that is laterally, since it cannot escape upward since there the crevices are filled up with the moisture descending into the cavity, nor can it escape downward because the moisture which has already fallen has closed up the crevices. There remain the openings at the side, whence this air, condensed and pressed down by the moisture which descends, escapes with the same slow rate of progress as that of the moisture which descends there: and this paste as it dries becomes stone, which is devoid of weight, and preserves the exact shapes of the creatures which have there made the mould, and encloses their bones within it.

He continues with the following explanation of the origin of sedimentary rocks, and how fossils become preserved in them:

> When nature is on the point of creating stones it produces a kind of sticky paste, which as it dries, forms itself into a solid mass together with whatever it has enclosed there, which, however, it does not change to stone but preserves within itself in the form in which it has found them. This is why leaves are found whole within the rocks which are produced at the bases of mountains, together with a mixture of different kinds of things, just as they have been left there by the floods from the rivers which have occurred in the autumn season; and there the mud caused by the successive inundations have covered them over, and then this mud grows into one mass together with the aforesaid paste, and becomes changed into successive layers of stone which correspond with the layers of the mud.
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> And if you wish to say that the shells are produced by nature in these mountains by means of the influence of the stars, in what way will you show that this influence produces in the very same place shells of various sizes, and varying in age, and of different kinds?
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> And how will you account for the very great number of different kinds of leaves embedded in the high rocks of these mountains, and for the algae, the seaweed, which is found lying intermingled with the shells and the sand?

And in the same way you will see all kinds of petrified things together with ocean crabs, broken in pieces, and separated and mixed with their shells.

Concerning the then prevalent idea that layers of fossil shells were vestiges of the flood of Noah, Da Vinci wrote:

If you should say that the shells which are visible at the present time within the borders of Italy, far away from the sea, and at great heights, are due to the Flood having deposited them there, I reply that, granting this Flood to have risen seven cubits above the highest mountain, as he has written who has measured it, these shells which always inhabit near the shores of the sea ought to be found lying on the mountain sides, and not at so short a distance above their bases, and all at the same level, layer upon layer.

Should you say also that the nature of these shells causes them to keep near the edge of the sea, and that as the sea rose in height the shells left their former place and followed the rising waters up to their highest level; to this I reply, that *in forty days the shells cannot travel so far;* that the cockle is a creature incapable when out of water of more rapid movement than that of the snail, or is even somewhat slower, since it does not swim, but makes a furrow in the sand, and, supporting itself by means of the sides of the furrow, will travel between 3 and 4 braccia (arm's length) in a day, and therefore with such a rate of motion it would not have traveled from the Adriatic Sea as far as Monferrato in Lombardy, a distance of two-hundred and fifty miles, in forty days, as he has said who kept a record of the time.

And if you say that the waves carried them there, they could not move by reason of their weight except on their base. And if you do not grant me this, at any rate allow that they must have remained on the tops of the highest mountains, and in the lakes which are shut in among the mountains, such as the lake of Lario, or Como, and Lake Maggiore . . . and others.

If you should say that the shells were empty and dead when carried by the waves, I reply that where the dead ones went the living were not far distant, and in these mountains are found all living ones, for they are known by the shells being in pairs, and by their being in a row without any dead, and a little higher up is the place where all the dead with their shells separated have been cast up by the waves . . . .

And if the shells had been in the turbid water of a deluge they would be found mixed up and separated one from another, amid the mud, and not in regular rows in layers as we see them in our own times.

Leonardo's keen observations on the differences between shells which grew *in situ* and those transported some distance from their point of origin led him to these observations:

> As for those who say that these shells are found to exist over a wide area having been created at a distance from the sea by the nature of the locality and the disposition of the heavens, which moves and influences the place to such a creation of animal life, to these it may be answered that—granted such an influence over these animals, it could not happen that they were in one line except in the case of animals of one species and of one age; and not the old with the young, nor one with an outer covering and another without its covering, nor one broken and another whole, one filled with sea sand, and the fragments great and small of others inside the whole shells which stand gaping open; nor the claws of crabs without the rest of their bodies; nor with the shells of other species fastened on them like animals crawling over them and leaving the mark of their track on the outside where it has eaten its way like a worm in wood; nor would there be found among them bones and fishes teeth which some call arrows and others serpent's tongues nor would so many parts of different animals be found joined together, unless they had been thrown up there upon the borders of the sea.
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> And the Flood would not have carried them there because things which are heavier than water do not float and the aforesaid things could not be at such heights unless they had been carried there floating on the waves, and that is impossible on account of their weight.
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> Where the valleys have never been covered by the salt waters of the sea, there the shells have never been found.

Da Vinci on Streams, Sediments, and the Sea

His many projects involving plans for defense of the city of Milan, for canals, irrigation ditches, and bridges led Da Vinci to a great study of streams, their valleys, and the sediment they carried to the sea. Much of this study he incorporated into his treatise on water.

On the nature of streams and their flow, he recognized the now accepted laws of stream velocity, the relationship between gradient and velocity, the gradual aging and meandering of streams, and the stream erosion cycle. The following quotations will illustrate these discoveries:

> Where the channel of the river is more sloping the water has a swifter current, and where the water is swifter

it wears the beds of its river more away and deepens it more and causes the same quantity of water to occupy less space.

Where the water is most rapid, it wears away most the bed on which it rubs. Where the water is most shut in, it becomes most rapid and in its passage wears away its bed most.

And the bed offers more resistance; this is why it moves more on the surface than at the bottom.

The farther water is away from its bed the freer will it be in its natural movement.

All the movements of streams of water which are equal in depth and declivity will be more swift at the surface than at the bottom, and more at the center than at the sides.

The shorter the course of the rivers the greater will be their speed. And also conversely it will be slower in proportion as their course is longer.

Every valley has been made by its river, and the proportion between valleys is the same as that between rivers.

The windings which the rivers make through their valleys as they leap back from one mountain to another cause the bank to form curves, and these curves move with the current of the water and in course of time seek out the whole valley, unless they are checked by the fact of it becoming increased in length and diminished in breadth.

The progress of the water is swifter when it falls at a greater angle.

Among straight rivers which occur in land of the same character, with the same abundance of water, and with equal breadth, length, depth and declivity of course, that will be the slower which is the more ancient. This may be proved with straight rivers. That will be most winding which is the oldest, and that which winds will become slower as it acquires greater length.

Valleys grow wider with the progress of time; their depth undergoes but little increase; because the rains bring as much soil to the valley almost as the river washes away, and in some parts more, in others less.

The sharp bends made in the enbankments of rivers are destroyed in the great floods of the rivers because the maximum current drives the water in a straight course. But as this diminishes it resumes its winding course, during which it is being continually diverted from one bank to another, and as it grows less the enbankment of the river becomes hollowed out.

The lowest parts of the world are the seas where all the rivers run. The river never ceases in its movement until it reaches the sea; the sea therefore is the lowest part of the world.

He made an amazing series of observations on the laws governing the transportation and deposition of sediments virtually all of which were later rediscovered and accepted by all students of sedimentation:

> The streams of rivers move different kinds of matter which are of varying degrees of gravity, and they are moved farther from their position in proportion as they are lighter, and will remain nearer to bottom in proportion as they are heavier, and will be carried a greater distance when driven by water of greater power.

He recognized the nature of gravels and conglomerates (shingle) and the reason for the roundness, as resulting from transportation along the bottom of the stream:

> And how will you explain to me the fact of the shingle (pebbles) being struck together and lying in layers at different altitudes upon the high mountains. For there is to be found shingle from divers parts carried from various countries to the same spot by the rivers in their course, and this shingle is nothing but pieces of stone which have lost their sharp edges from having been rolled over and over for a long time, and from the various blows and falls which they have met with during the passage of the waters which brought them to this spot.
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> When a river flows out from among mountains it deposits a great quantity of large stones in its gravelly bed, and these stones still retain some part of their angles and sides; and as it proceeds on its course it carries with it the lesser stones with angles more worn away, and so the large stones become smaller; and farther on it deposits first coarse and then fine gravel and after this big and then small shingle, and after this follows sand, at first coarse and then fine: and thus continuing, the water turbid with shingle and sand reaches the sea.

or, by the constant action of waves along the shore, pounding at the rocks:

> All the outlets of the waters which proceed from the mountain to the sea carry stones from the mountains with them to the sea; and by the backwash of the ocean surges against their mountains, these stones were thrown back towards the mountain; and as the waters moved towards the sea and returned from it the stones turned with them, and as they were rolled back their corners struck together, and such parts of them as offered least resistance to the blow were worn away and made stones without angles, of a round

shape, such as are to be seen on the shores of Elba. And those remain bigger which are carried the least distance from their native spot, and in like manner the stone becomes smaller which is transported farther away from the aforesaid spot, for in the course of its progress it becomes changed to fine shingle and then to sand and finally to mud. After the sea had receded from the aforesaid mountains the salt deposit which it left behind with the other moisture from the earth formed a compound with the shingle and sand so that the shingle became changed to rock and the sand to tufa.

Know that stones are rolled over by water because this water either surrounds or flows over them. If it surrounds them it meets again beyond them and intersects, hollowing out the soil or sand beyond the stone, and this after being thus laid bare begins to roll of itself. And if the water flows over the stone then after it has done so it falls in the same line, and by the force of its impetus penetrates from the surface to the base of the other water, and gnaws and tugs and drags away the stone from the opposing obstacles with the result that this also begins to roll, and so continues from place to place until it traverses the whole river. And if a lesser stone should stand in its path the water uncovers it by the same process and does the same, and in this way stones are rolled over in the beds of flowing rivers.

If the mountains had not remained in great part uncovered by the waters, the courses of the rivers would not have been able to carry so much mud into the sea as exists at a great elevation, mingled with the animals which have been enclosed by it.

All the things which are lighter than sand will be left in the lower part of the river underneath the beginning of the fall of the wave.

Where the water has the least movement the surface of the bottom will be of the finest mud or sand.

Sand and other light objects follow and obey the twists and turns of the eddies of the water while the large stones move in a straight line.

Turbid water does more harm to the banks than clear water, and more at the base than at the top, because it is heavier and thicker.

That part of the sand which is nearest to the impact of the falling water will be finer that the rest.

The large shingle will be farthest away from the blow.

Where the water has a stronger current the shingle is larger. All the detached shingle will turn its largest side slantwise against the course of the water.

All light things gather together in the center of the eddies, that is at the bottom.

As to the laws governing the capacity of streams of varying velocity to carry various sizes of particles, he writes:

> That thing which is lighter will be carried farther by the rivers from the place whence its waters snatched it away; and so that which is heavier will be removed a less distance from the place at which it was separated. That percussion of the waters carries away more of the bank of rivers which strikes this bank at more equal angles; and so conversely it will carry away less when the angles are more equal.
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> When the water in the floods commences to find a place where it can flow, it begins with its feeble inundations to strip and carry away the lightest things, and deposits them where its course becomes feeble, then as it grows it carries away the heavier things such as sand, and carries them over the former things and there leaves them, and even through the water should not increase, by the mere fact of its continuance, it proceeds by degrees to carry away the things from the place where it flows; but by reason of their weight it cannot carry them so far forward as the first lighter things, and if it carries away the heavier things it deposits them proportionately near to the spot from whence it took them.
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> Where the river is constricted, it will have its bed stripped bare of earth, and the stones or tufa will remain uncovered by the soil.
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> Where the river widens, the small stones and the sand will be deposited.
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> Where the river widens considerably, there will be discharged the mud or the ooze and bits of timber and other light things.
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> Where the waters separate, the sand and ooze will be deposited, and the bed will be raised in the shape of the half of a ship inverted.
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> Where you find much sand you will at the end of it in front or behind, shingle or bare tufa.
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> It is not denied that the Nile is always turbid as it enters the Egyptian Sea, and that this turbid condition is due to the soil which this river carries away continually from the places through which it passes, and this soil never returns back nor does the sea receive it except just to cast it back on its shores: behold the ocean of sand beyond Mount Atlas where it was once covered with salt water.
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> The stratified rocks are created in the vast depths of the seas because the mud which the storms detach from the sea coasts is carried out to the deep sea by the recoil of the waves; and after these storms it is deposited on the bottom of the sea; and as no storm can penetrate the sea on account of the great distance that it is below the surface it lies there motionless and becomes petrified; and sometimes it remains in

> the form of white clay which serves for making pots; and thus with blocks set at different angles it is made up of layers of as many different thicknesses as are the differences in the storms whether greater or less.

Da Vinci also made the following interesting observation concerning soil erosion:

> The rivers make greater deposits of soil when near to populated districts than they do where there are no inhabitants. Because in such places the mountains and hills are being worked upon, and the rains wash away the soil that has been turned up more easily than the hard ground which is covered with weeds.

Da Vinci on Internal Earth Forces

The observations on fossil shells previously quoted led Da Vinci to some brilliant conclusions concerning the great internal forces which cause the rise of mountains, the sinking of the sea, and the elevation of the floor:

> The shells of oysters and other similar creatures which are born in the mud of the sea testify to us the change in the earth round the center of our elements. This is proved as follows: the mighty rivers always flow turbid because of the earth stirred up in them through the friction of their waters upon their bed and against the banks; and this process of destruction uncovers the tops of the ridges formed by the layers of these shells, which are imbedded in the mud of the sea where they were born when the salt water covered them. And these same ridges were from time to time covered over by varying thicknesses of mud which had been brought down to the sea by the rivers in floods of varying magnitude; and in this way the shells remained walled up and dead beneath this mud, which became raised to such a height that the bed of the sea emerged into the air.
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> And now these beds are of so great a height that they have become hills or lofty mountains, and the rivers which wear away the sides of these mountains lay bare the strata of the shells, and so the light surface of the earth is continually raised, and the antipodes draw nearer to the center of the earth, and the ancient beds of the sea become chains of mountains.

Careful reading of the following statements from his notebooks clearly indicates to the writer that Da Vinci first conceived the fundamental principle of isostatic adjustment between continents and ocean basins: the continents rising as erosion strips away their masses, and transferring this great weight of sediments to the ocean basins, thus depressing them and forcing the continents even higher. It is this important principle which Dutton (1872) re-enunciated and named isostasy. On isostasy, Da Vinci commented:

> The center of the world continually changes its position in the body of the earth fleeing towards our hemisphere. This is shown by the above-mentioned soil which is continually carried away from the declivities or sides of the mountains and borne to the seas; the more it is carried away from there the more it becomes lightened and as a consequence the more it becomes heavy where this soil is deposited by the ocean waves, wherefore it is necessary that such center changes its position.
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> That part of the surface of any heavy body will become more distant from the center of its gravity which becomes of greater lightness.
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> The earth therefore, the element by which the rivers carry away the slopes of the mountains and bear them to the sea, is the place from which such gravity is removed; it will make itself lighter and in consequence will make itself more remote from the center of gravity of the earth, that is, from the center of the universe which is always concentric with the center of gravity of the earth.
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> The summits of the mountains in course of time rise continually.
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> Because the centre of the natural gravity of the earth ought to be in the center of the world, the earth is always growing lighter in some part, and the part that is lighter pushes upwards, and submerges as much of the opposite part as is necessary for it to join the center of its aforesaid gravity to the centre of the world; and the sphere of the water keeps its surface steadily equidistant from the center of the world.

Conclusion

It is quite obvious from the preceding selection of quotations from the notebooks of Leonardo da Vinci that his observations and studies in various aspects of earth processes, the origin of sediments, the hydrology of streams and history of stream valleys, and on the true nature of layers of fossils and their significance in earth history, all constitute a remarkable contribution to the science of the earth.

The writer has been able to present only a few of the many geological contributions of the mastermind of the Renaissance, but it is hoped that enough has been included to warrant his contention that Leonardo da Vinci can be accorded the title of pioneer geologist.

Much of the value of his early discoveries was, of course, lost as they lay fallow for over 300 years in the mass of illegible "mirror-writing" which constituted the bulk of the results of his scientific genius, and were rediscovered, or are being rediscovered, independently by later earth scientists. Thus the science of geology hastens to join her sister sciences in a tardy though justifiable tribute to this great intellect of the Renaissance, and to know him as one of the founding fathers of our science.

REFERENCES

Mac Curdy, Edward, *The Notebooks of Leonardo Da Vinci,* New York: Geo. Braziller, 1954, 1247 pp.

Mac Curdy, Edward, *The Mind of Leonardo Da Vinci,* New York: Dodd, Mead & Co., 1940, 359 pp.

Southern Illinois University, *The Resources of Leonardo Da Vinci,* Ed. by G. P. Plochman, Carbondale, Ill., 1953.