July 6, 1993 Letter from Brown to Morris and Austin – Setting the Record Straight

Grand Lake and Breached-Dam Theories: Setting the Record Straight

by Walter T. Brown, Jr.

(Originally written on July 6, 1993; last amended on 9 November, 1993)

The Problem.

Over the last three years I have become increasingly puzzled and disturbed by several calls from people who have heard others imply that I plagiarized some work of Dr. Steve Austin of the Institute for Creation Research (ICR). They claim that I took (or at best, did not acknowledge) Austin's ideas that Grand and Hopi Lakes overflowed and carved the Grand Canyon. The reports are usually vague. Therefore, I have generally ignored the problem. However, I wrote Dr. Henry Morris on March 13, 1991, and asked him, among other things, to look into any unsupported allegations coming out of ICR.

One such incident, recently verified, was witnessed by Dr. and Mrs. Douglas Block of Rockford, Illinois. They attended Austin's Sunday evening talk at The People's Church in Beloit, Wisconsin, on November 3, 1990. After the program, the Blocks had a "very congenial conversation" with Austin. Austin asked Dr. Block, a geologist, what his plans were after retirement. Dr. Block said he wanted to do some work with Walt Brown. Both Dr. and Mrs. Block remember that Austin suddenly looked angry and said that Brown had taken some of his material on the Grand Canyon. Austin then gave the Blocks a "cold shoulder" and walked away. The Blocks left the church "stunned, upset, and aghast."

The most recent allegation was relayed to me by Dr. Bob Gentry on June 10, 1993. Gentry, who was reluctant to mention his source, said that Dr. Russell Humphreys told him that I should acknowledge Austin's prior work. While Humphreys never used the word "plagiarism," Gentry assured me, and later told Humphreys, that plagiarism was clearly implied. Partly for this reason Humphreys declined to work with Gentry on a film project. Humphreys confirmed this to me by phone on June 28th and 30th, although he admitted he did not know of my work on the Grand Canyon. Humphreys worked closely for Austin as a guide on nine Grand Canyon tours. Although Gentry told Humphreys he did not accept his allegation, it presented Gentry with a liability. If Humphreys were correct, it could discredit Gentry and his project, involving great effort and expense.

I have known since August 1990 that Austin was proposing explanations that were remarkably similar to mine. Even the name I selected a year earlier, Grand Lake, was the same. Raising the issue of priority seemed petty and egotistical, so I tried to ignore the matter. The important thing was getting the information out. We are working for the same Lord and Creator. I have never gotten upset when someone fails to reference my work—or even when they claim it as their own and copyright it. When this happens, I consider it a compliment. However, if someone does this and he or others working with him announce that I stole it, then I must act. This means hitting the priority issue "head on." Reputations and a person's effectiveness are easily damaged by such loose talk, especially when the allegations are made behind your back.

Such behavior hurts the creation movement. People who are committed to Biblical inerrancy and careful science occasionally have honest disagreements. Most disagreements are due to our differing backgrounds, specializations, callings, and circumstances. With good communications among ourselves, these differences should strengthen the creation movement. However, poor communication can cause harmful disagreements. Backbiting is the worst form of communication. If you have an objection, you should first go to the alleged offender in private (Mt 18:15-17). If he does not acknowledge his errors then or after hearing one or two additional witnesses, other Christians should be told. Notice, in these verses, that this unpleasant procedure was not a suggestion.

Setting the Record Straight.

On June 18, 1993, I wrote Austin and asked if these allegations were true. Austin telephoned me and

said that he had not told anyone that I stole any of his ideas. He thought people who heard his ideas before mine might have assumed that I took them from him. Austin then wrote me on June 21st and explained more specifically:

> I can understand why some people say that you plagiarized my work. We came to the same conclusion, but my conclusion preceded yours by two years. I believe that we came up with the theory independently. I am not saying that there is any plagiarism here. It is the appearance that leads people to say this.

Since Austin feels he has precedence by two years (a claim that I believe is incorrect), he may have left the impression, knowingly or unknowingly, with others that I plagiarized. Austin ended his letter by asking me to "set the record straight." This, then, is the purpose of this report.

Michael J. Oard has just published a critique of what he calls "the breached-dam" explanation for the formation of the Grand Canyon.[1] Although Oard had read Dr. Emmett Williams, et al.'s article summarizing my 1989 explanation for Grand Canyon,[2] Oard had not read my explanation. Oard aimed his critique at Austin's 1991 explanation in the *Institute for Creation Research Grand Canyon Field Study Tour Guidebook*. Oard raised five geological problems and suggested how the lakes, whose waters supposedly carved the Grand Canyon, were filled. As I explained by phone to Oard on June 26th and to Williams (who reviewed Oard's paper) on June 25th, those five problems are easily explained, and the basins were automatically filled at the end of the Flood. I hope Oard's article will not diminish interest in "the breached-dam" idea or confuse the priority issue even more.

I cannot correct the record by a simple letter to the editor of the *Creation Research Society Quarterly* or even by publishing a counter article. The brief justification for the Hydroplate Theory, which sets the stage for the Grand Canyon's formation many years after the Flood, required 25 pages.[3] A complete explanation for the formation of the Grand Canyon, which I someday hope to write, would be of comparable length. I felt fortunate in 1989 to summarize the "Grand Lake Explanation" (GLE) in about one page, after explaining the Hydroplate Theory. Other details and supporting discoveries, when explained, will make the GLE even more obvious.

After talking and corresponding with Austin and reading his *1988 - 1990 Guidebooks*, I can now present the chronology of our various ideas. If Austin, Henry Morris, or others can show errors or omissions in what I have written, I will happily correct this record or attach their comments. The objective of this paper is to accurately determine who disseminated what and when. The intended reader is anyone who might have heard any misinformation or who wonders when the "dam-breaching" ideas were proposed, and by whom.

A Summary.

After carefully studying these matters, I have concluded:

1. Austin may not have said I "stole or plagiarized" his ideas concerning the formation of the Grand Canyon. However, others clearly remember him saying that I had taken his ideas.
2. The proposal that a lake's natural dam was breached and its waters carved canyons along the Colorado River dates back to Newberry in 1861. Austin read a similar proposal by Blackwelder, published in 1934. Neither Newberry nor Blackwelder specified any lake's location, how such a large lake could have formed, or where or how they were breached.
3. In 1984, Austin published a paper describing how a 100-foot deep canyon formed when Spirit Lake suddenly spilled out near Mount St. Helens.[4] Austin described this erosion channel as a "little Grand Canyon."
4. Dr. Edmond W. Holroyd, III, in December 1986, realized that the sudden release of the waters of a giant lake may have carved the Grand Canyon. On February 26, 1987, Holroyd sent Austin a detailed color photograph of where such a lake would have been. The lake was drawn by a computer tracing the 1700 meter (5577 foot) contour line.

5. In the *1988 and 1989 ICR Guidebooks*, Austin wrote that he was entertaining the possibility that the Grand Canyon formed by the breaching action of a lake east of the canyon.
6. Independently of Holroyd, in the spring of 1988, I determined that a large lake (which I named Grand Lake) with a surface elevation of 5700 feet, once existed in southeastern Utah, parts of Arizona, New Mexico, and Colorado. (See the figure on page 10.) This was confirmed by identifying about 5 or 6 geological features near or just below that elevation. I concluded that this lake, another extinct lake east of the Grand Canyon (which earlier geologists had named Hopi Lake), and other lakes higher up in the Colorado River drainage system helped carve the Grand Canyon. On September 16, 1988 in St. Paul MN, I began speaking and broadcasting nationally on the GLE.
7. In February 1989, Austin inserted a page into ICR's *1988 Guidebook* showing Holroyd's lake, which Austin knew was defined by the 5577-foot contour line. Under that figure, Austin wrote that it "was blocked at the 5700-foot elevation" and it "breached its dam to form Grand Canyon." ICR republished that *Guidebook* in February 1989 with a 1988 copyright. Holroyd gave Austin permission to publish Holroyd's map in the *1989 Guidebook* and suggested how proper acknowledgement could be made. Austin did not mention Holroyd; however, Holroyd does not fault Austin for that.
8. I published a summary of the GLE in August 1989 in the 5th edition of "*In the Beginning . . .*". Austin purchased that book weeks later in St. Paul, MN.
9. Major changes were made to ICR's *1990 Guidebook*. There was no more tentativeness. It became very specific in saying that the Grand Canyon formed by dam-breaching. Grand Lake was shown and named for the first time in an ICR *Guidebook*—without reference.
10. Austin believes Hopi Lake to the east of the Grand Canyon initiated the events that carved the Grand Canyon. I believe a series of lake dumpings cascaded, like falling dominoes, ending with the dumping of Grand Lake and finally Hopi Lake. Those dumpings would have eroded enough mass off northern Arizona to cause an instability in the earth's crust which produced the Kaibab Upwarp. (I will not explain here the theoretical[5] or experimental[6] justification for this buckling instability.) Today that upwarp is over 1400 feet higher than either Grand or Hopi Lake ever was. Had the Kaibab Upwarp existed before the lakes dumped, it would have diverted their waters away from the Grand Canyon.

Early Proposals of Breaching Events.

The earliest hint of this "breaching" idea along the Colorado River was by John Strong Newberry in 1861. Newberry was the geologist on the Ives expedition of 1857-58, sponsored by the U. S. War Department to study the lower Colorado River. "Newberry believed that the mountain ranges had impounded the river in a series of basins which, on overflowing, had led to the cutting of the canyons . . . ' through which its turbid waters now flow with rapid and almost unobstructed current from source to mouth.'"[7] In May of 1988, I located Newberry's report of that expedition at the Grand Canyon Library but unfortunately could not find anything in it to substantiate Newberry's statement. Williams et al. apparently located Newberry's explanation.[8] Therefore, *Newberry was probably the first to propose that at least some canyons along the Colorado River formed by the breaching of natural dams.*

Professor J Harlen Bretz popularized the fact that breached dams can quickly and catastrophically form canyons.[9] In 1923, Bretz proposed that the Channeled Scablands of eastern Washington State formed when a large lake spilled over a glacial dam. The dam quickly eroded, spilling out a volume of water equal to about half that now in Lake Michigan. For about 40 years, opposition raged against Bretz for his catastrophic and heretical views. Geologists dramatically accepted Bretz's explanation in 1962, establishing ever since the "dam-breaching" mechanism in the minds of geology students and some of the general public. Many people have observed, and I have personally seen, that the Channeled Scablands bears some resemblance to a miniature Grand Canyon.

Austin first learned of dam-breaching proposals along the Colorado River from a 1934 paper by Eliot Blackwelder[10]. Blackwelder placed these events in the Pleistocene period but did not specify the location of the lakes or many other related details.

My First Contacts with Austin.

In January 1976, I read an excellent *Impact* article by Stuart E. Nevins of ICR. I traveled that summer to ICR in part to meet Nevins and discuss some similar ideas I had. I asked Henry Morris at lunch if I could see Nevins, the fictitious name Austin was writing under. Morris only told me that Nevins was away for the summer—not that Austin was writing under that name. Later, I was quite surprised to learn that Nevins was really Steve Austin. It is unusual for a scientist, or even a graduate student working under evolutionist professors, to write under a pseudonym.

In February of 1981, I flew from Chicago to ICR to discuss several organizational matters of mutual interest and to meet some of their people. Austin entered the room where several of us were talking. Paul MacKinney, who had accompanied me from Chicago and who knew Austin, asked me to explain to Austin what has become known as the Hydroplate Theory. Austin said that he only had five minutes before a driver would arrive to pick him up, but he would listen. I declined, saying that an explanation would take too long. Austin insisted that I give the explanation, because he could understand it in five minutes. He said that he had heard everything that had been proposed about the Flood, and he would quickly understand what I was saying. Again, I declined. Everyone in the room urged me to begin, so I did. Before I finished the first of about fifty points, Austin interrupted and began giving his experiences supporting what I had just said. After he talked for several minutes, he stopped, put on his coat, and abruptly left to catch his ride.

The first creation seminar I ever gave was in March 1981. Mr. Terry Mondy, who attended, called a week or so later. He was very enthusiastic about the Hydroplate Theory and urged me to publish it. He said that he had called Austin at ICR and urged him to look into it. Austin's response was, "I wish these non-geologists would stay out of our business." Mondy recently confirmed these details.

Hopefully, Austin has outgrown these attitudes that convey arrogance. Nevertheless, it was obvious that he had no interest in exchanging ideas with me. My next dealing with Austin was the letter I sent him on June 18, 1993.

1986 - 1987.

In August 1986, Dr. Edmond W. Holroyd, III, met Austin at the International Conference on Creationism in Pittsburgh. He told Austin his interests in explaining the absence of rock fragments (talus) at the base of many cliffs on the Colorado Plateau. If the cliffs eroded over millions of years, the base of the cliff should be thickly littered with boulders and their crumbling remains. Piles of crumbling boulders should extend thousands of feet from the base of each cliff. Holroyd wrote a short article about this a year later. He suggested that a vast lake possibly existed east and north of the Grand Canyon.[11] He wrote:

> Another possibility for talus removal is shoreline destruction of rocks by wave action . . . . One could also imagine a series of lakes if the Colorado River was plugged by high ground between the Kaibab and Coconino Plateaus at about the Grand Canyon visitor Center. A lake surface at about the 1700 meter (5600 ft) level could be supported by the present regional topography without the water spilling out over another divide to the north. The resulting series of lakes along the Colorado, Little Colorado, Green, and San Juan Rivers would resemble several of the Great Lakes in size. (Some believe that the sudden release of such a great quantity of water through a fault-generated crack between the north and south rims of the Grand Canyon near the Visitor Center is responsible for the bulk of the carving of the Grand Canyon.)

In February 1987, Holroyd sent Austin a color photograph of a computer generated map showing where a lake would be whose surface was 1700 meters (actually, 5577 feet) above sea level. *It may be the first attempt to identify where a lake or lakes were that carved the Grand Canyon.* Austin kept that important photograph in his office for the next two years.

In 1990, Holroyd presented a more detailed paper on this topic of missing talus at the International Creation Conference in Pittsburgh.[12] In that paper he included a copy of his map. On June 25, 1993, I telephoned Holroyd, learned of his original work for the first time, and the details I have just described.

One reviewer of Holroyd's 1990 paper was Dr. Bernard E. Northrup. He wrote: "I originally had proposed that the Kaibab/Coconino uplift [what Austin calls the Kaibab Upwarp] itself had been that temporary dam. However, presently I think that Walter Brown is correct in proposing that the Vermilion Cliff/Echo Cliff uplift was the barrier behind which the ice waters impounded."[13]

1988 - August 1989: Brown's Work.

In January 1988, I began a year of study on the Grand Canyon. It included: completing a geology course on the Grand Canyon at Arizona State University, reading dozens of books and documents on the Grand Canyon, conducting many field trips into the canyon and especially into the surrounding region (southeastern Utah, western Colorado, and northeastern Arizona), and taking a raft trip down the Colorado River lead by a prominent geologist and author on the Grand Canyon. By March of 1988, after considering and later rejecting five different explanations for the Grand Canyon, I began to formulate a new and specific explanation for its formation which I will call the "Grand Lake Explanation" (GLE).
To me, the most important test of a theory (or explanation) is its ability to make successful predictions. Several surprising predictions could obviously be made with the GLE, so from March to June of 1988 I searched for several of these unusual phenomena. Most were found. One that eluded me for several months was a vertical (slightly reversed) fault that had to (1) cut across Marble Platform at a certain location, (2) trend in the proper direction, and (3) be visible in several very inaccessible parts of Marble Canyon. The Arizona State Geologist told me that no fault of any kind was recorded near there. It was clear to me that if this fault did not exist, the GLE was probably wrong. Detailed aerial photos were not much help. Before beginning the difficult task of hunting further, I asked Dr. Block, who had been a geology professor for 30 years, to fly to Phoenix so I could see if he concurred with my prediction. He did, and he concurred. Weeks later, after several false starts, I found the fault. Friends, who know the tedious details which I am sparing you, call it "Walt's Fault." I will never forget the find, because it almost cost me my life (dehydration, trapped inside a box canyon high on the south wall of Rider Canyon). I went into the backcountry with permission and with more than the recommended water, but foolishly unaccompanied, just a week before my daughter's wedding. After finding the fault, I became, and still am, fairly confident that I know at least the general outlines of how the Grand Canyon, and many other canyons, formed. The keys to this understanding lie primarily outside the Grand Canyon, not inside. I began preparing photos and explanations for a series of seminars and radio programs I would give that fall.

In April 1988, I read the *1988 Guidebook* prepared primarily by Austin. He was "supposing" (page 41) that the Grand Canyon formed by the breaching of an ancient lake east of the canyon. He said,

> "Lately, I've been supposing that the plateau land in northern Arizona was uplifted rapidly and that the drainage basin upstream was blocked by that plateau. That elevated plateau would have formed a gigantic natural dam with a lake east of the present Grand Canyon. Thin sedimentary deposits from the lake occur east of the canyon. Modern experience with man-made dams shows that when they fail, they fail catastrophically. I supposed that the northern Arizona dam also failed rapidly allowing the impounded lake to drain westward over the plateau causing significant erosion to the Grand Canyon."

"A catastrophic drainage model for the origin of the Grand Canyon needs to be supported by geologic evidence."

Austin then listed many features in the canyon which show that rapid erosion occurred. Most are discussed in the abundant writings on the Grand Canyon. Some were explained to me by Dr. Art Chadwick who visited my office in the spring of 1988. Art spent over 700 days in the canyon over a 13-year period. Austin said nothing about why that 30-mile thick dam failed, what specifically lifted the Kaibab Plateau, or why it rose rapidly. The force and energy requirements would have been awesome. Austin knew from the writings of Howel Williams,[14] who named the region Hopi Lake, that the valley of the Little Colorado River contained lake-bottom sediments. Dr. Block and I verified in June 1988 that these sediments existed in the Hopi Lake region up to almost the 6000-foot elevation. We also made a similar verification in the basin that held Grand Lake.

Most of my speaking engagements are scheduled in the fall. About 15 were in the fall of 1988. The first, a radio broadcast on KTIS Radio in St. Paul, Minnesota on September 16, 1988, stands out in my mind. It was rebroadcast over dozens of affiliated stations in the United States. The tape of that broadcast was advertised and sold by the station, and I have mailed out over 200 copies. (A copy is inclosed as Attachment 1.) Just a few minutes into the program, I described my thinking on the Grand Canyon and my work during the previous six months. I received many phone calls afterwards asking for more details, which I always provided. In the program, I discussed much of what I later published in August 1989. That fall, I frequently spoke of the 5700-foot Grand Lake. On September 18, 1988 at Northwestern College in St. Paul, I gave a two-hour presentation on the Grand Canyon's formation.

1988 - August 1989: ICR's *1989 Guidebook*.

In February of 1989 Austin published the *1989 Guidebook*. I first saw it on June 23, 1993, when Austin sent it to me. The only paragraphs in it (page 51) concerning a rapid means for forming the Grand Canyon are reproduced below.

Erosion of the Grand Canyon--A geologist's Personal Reflections

THE CATASTROPHIC DRAINAGE THEORY
My mind began again to consider the geologic evidence at Grand Canyon. As explained before, it seems certain that the Kaibab Upwarp was established before the Colorado River was positioned across northern Arizona. Could the uplift of the plateau have created a drainage basin east of Grand Canyon which completely filled with flood water? Could the large dam created by the Kaibab Upwarp have been breached allowing the "lake" behind it to drain over the plateau through northern Arizona initiating the erosion of Grand Canyon? [Austin's emphasis]

There is evidence that an impounded mass of water existed on the east side of the Kaibab Upwarp. Geologists call the sedimentary deposits restricted to the east of Grand Canyon the Bidahochi Formation. They contain regular layers of silt and sand which look like lake deposits which would have been deposited from accelerated erosion in the drainage basin now occupied by the upper Colorado River. These are thin strata that represent a short time geologically (classed as Pliocene by many geologists).

The most significant item in Austin's book (again, which I first saw on June 23, 1993) was a full page map on page 54. I now know it is Holroyd's map (Attachment 2), although there was no reference to Holroyd in the *1989 Guidebook*.[15] (In the *1990 Guidebook*, Holroyd was referenced only by: "Plotted by Edmond W. Holroyd, III." This minimized Holroyd's real contribution.) Holroyd's map was similar

to the one I published six months later for the formation of the Grand Canyon (see page 10). Under Holroyd's map in the *1989 Guidebook*, Austin placed the following statement.

> A computer was asked to draw the shoreline of the lake which would form behind the Kaibab Upwarp if the Grand Canyon were blocked at the 5,700-foot elevation. The lake which would form is shown above. It would contain the water of three Great Lakes. This computer-generated lake approximates the outline of the ancient lake which breached its dam to form the Grand Canyon.

This then is Austin's writing on how the Grand Canyon formed five months after I began speaking nationally on the GLE but six months before my publication of August 1989. Consider several points.

1. Where did Austin get "the 5700-foot elevation" number? Since the spring of 1988, I have always used that number for the height of Grand Lake.[16] The rationale for that number is complex. Since it is not one that someone else would likely conclude, it seems probable that Austin got that number from me. This means that he probably heard of my explanation sometime after I began talking publicly about it (September 16, 1988) but before his letter to Holroyd on January 23, 1989 (see endnote 15).

   What was so special about 5700? The most obvious way to approximate Grand Lake's elevation is the way Holroyd did and the way Austin told me on the phone it was derived. See how high water would rise today if a very tall dam were built along the Colorado River between Vermilion Cliffs and Echo Cliffs. The answer is very close to Holroyd's number of 5577 feet.[17] However, I found many geologic features within a 150 mile radius of the Grand Canyon that I felt strongly showed that a lake was once there, and it dumped rapidly. The elevations of those features were closer to 5700 feet. Therefore, weighing all the evidence and realizing that the topography and elevation of the land differs slightly from what it would have been before Grand Lake dumped, I arrived at 5700 feet. My approach could be wrong and Holroyd's right. The point is that I arrived at a unique number. I carefully derived this number because several hundred hours of field and artwork would later depend on it.

   Map publishers usually place intentional errors on their maps. Therefore, if anyone copies the map, they will copy the error. Courts have used this to show copyright infringement. The elevation I have always used for Grand Lake (5700 feet) was such a "trademark" and Austin used it.

2. The second point is that Austin stated in our phone call and in his June 21st letter that his map was copyrighted in 1988 and written in 1987, one and two years before mine. He wrote:

   > Enclosed is the April 1989 version of the *ICR Grand Canyon Field Study Tour Guidebook* (copyright 1988), the text of which is a reprint of the *April 1988 Grand Canyon Field Study Tour Guidebook*. That text was written in November 1987 and the book printed in February 1988. It contains clear language describing the theory of a breached dam. These publications would appear to prove that I am the first creationist to propose the breached dam theory for the origin of Grand Canyon.

   This is misleading. Except for the text under Holroyd's map, Austin's comments on "breaching" were simply musings: "My mind began again to consider...", "Could the uplift of the plateau have created...", "Could the large dam created by the Kaibab Upwarp have been breached...", etc. Yes, part of one sentence under the map, which Austin added in February 1989, was specific: ". . . the ancient lake which breached its dam to form the Grand Canyon." However, that is an assertion, not "clear language describing the theory of a breached dam." Proposing a theory involves explaining many cause-and-effect details and answering many related questions.

3. Newberry and Blackwelder first suggested that breached dams carved canyons on the Colorado River. Proving that you are "the first creationist to propose the breached dam theory for the origin of Grand Canyon," as Austin claims, is irrelevant. Discoveries are only made once. For example, is it important to know the first creationist to conclude that $E = mc^2$?

4. Having a 1988 copyright on a book that was slightly modified and published in 1989 reminds one of "backdating a letter or check." The modifications were significant. Chapters 7 and 8 were obviously modified because they listed the April 1989 itinerary and participants for the 1989 tour. One other change was inserting Holroyd's full-page map, placing the note below it and then eliminating enough references at the end of that section so the page numbers for the rest of the book would not have to be changed. What overriding incentive caused Austin to go to the considerable trouble to make just this isolated change? On June 21, 1993, Austin emphasized the 1988 copyright in our phone conversation and in the paragraph of his letter (shown above). Did he put a 1988 copyright on the *1989 Guidebook* (and published in 1989) because he wanted to establish a 1988 priority?

5. Austin's June 21st letter to me continued

> Who was the first creationist to propose that a large post-Flood lake existed in southeastern Utah? I was working with Dr. Ed Holroyd (Arvada, Colorado) to do the terrain analysis which led to the plotting of the lake shown in illustration on page 54 of the *1989 Grand Canyon Guidebook* (published in February 1989). As best as I can remember this plotting was done in 1987, but I would need to check my archives of correspondence. I am uncertain when the first hand sketch was made of the figure which was later redrawn to appear on page 54. There had to be a significant period of time between the hand drawing and the finished figure. Our artist at ICR is very slow at finalizing my sketches. **It would appear that I preceded you by two years on recognition of the lake in southeastern Utah.** [Austin's emphasis]

No. Holroyd preceded both Austin and me by about two years in proposing where a large lake that carved the Grand Canyon might have been. Again, Austin is taking credit for Holroyd's original work. Saying that he "was working with Dr. Ed Holroyd (Arvada, Colorado) to do the terrain analysis . . . ." is an understatement that hides Holroyd's true contribution. Holroyd drew the first map of a single 5577-foot lake and proposed that it might have carved the Grand Canyon. Holroyd reached this conclusion in December 1986, has a slide of it that is stamped January 1987, and mailed it to Austin in February 1987.[18] Only by taking credit for Holroyd's work can Austin make the statement he places in bold above. (Note: Holroyd does not object to Austin's use, without credit, of Holroyd's map.)

Besides, proposing where a lake was that dumped and formed the Grand Canyon is just the first step. To be credible, you must answer many other questions. Where and how was the natural dam breached? Circumstantial evidence is fine, but can you show that a vast lake would have been there and was there, that a dam would be breached, that it would have catastrophically dumped, and that the volume of water was sufficient to carry the huge volume of Mesozoic and Paleozoic sediments off northern Arizona?

6. Austin's 1989 statement under the map contains several minor errors which he corrected in his *1990 Guidebook*. First, he said that his figure describes one lake. Instead, it represents three of the many lakes that were once impounded on the Colorado Plateau. I showed two of them, Grand and Hopi Lakes, in my figure. They are separated by the 7,000-foot Kaibito Plateau near where Austin placed the label "Black Mesa." Another minor point is that the impounded Hopi Lake could rise about 5,950 feet above today's sea level, not the 1700 meters (5577 feet) shown on the map.

7. Austin does not say why "it seems certain that the Kaibab Upwarp was established before the Colorado River was positioned across northern Arizona." Nor does he explain how the "drainage basin east of Grand Canyon" (which ICR's *1990 Guidebook* clarified to mean Hopi Lake) could ever breach the Kaibab Upwarp. That upwarp is about 7,400-foot high. Water will not spontaneously flow uphill 1,400 vertical feet. Austin was puzzled by it then, and he still is today. His best guess still is that it was breached by "piping"— underground seepage. It should be clear that a negligible amount of water would seep through the 30-mile wide Kaibab Upwarp, especially when its rock, cemented by limestone, has such slight porosity. Slow seepage removes very little material. Austin understands my objection.

   Finally, breaching by surface flow (overtopping) is much more likely if the dry part of a natural dam is vertical and tall, as are man-made dams, and as was the case with one-half-mile-high Vermilion/Echo Cliffs. Overtopping most water divides (topographic saddles) will not produce catastrophic dumping. There is just too much frictional resistance to the initial cutting action on too gradual a slope. The lake's level drops too fast for a given amount of vertical rim erosion.

August 1989.

In August of 1989, I published the Grand Lake Explanation (GLE).[19] Since it was brief, I will repeat it below. The relevant statements occur three places in a 26-page section entitled "The Fountains of the Great Deep."

> Page 58:
> Have you ever wondered how the Grand Canyon formed? After examining much broader issues in the following pages, a surprisingly simple explanation will be given. [The explanation of the Hydroplate Theory that followed page 58, is very helpful in understanding how the Grand Canyon formed.]
>
> Pages 75-76:
> The drainage of the waters that covered the earth left every continental basin filled to the brim with water. Some of these post-flood lakes lost more water by evaporation and seepage than they gained by rainfall and drainage. Consequently, they shrank over the centuries. A well-known example was former Lake Bonneville which has shrunk to become the Great Salt Lake.
>
> Through rainfall and drainage from higher terrain, other lakes gained more water than they lost and thus overflowed their rims at the lowest point. Just the slight erosion of a rim allowed more water to flow over it. This eroded it even deeper and caused even more water to cut it faster. Thus, the downcutting process accelerated catastrophically. Eventually, the entire lake dumped through a deep slit which we today call a canyon. These waters emptied into the next lower basin, causing them to overflow their rim and create another canyon. It was like falling dominoes. The most famous canyon of all, the Grand Canyon, was caused primarily by the dumping of what we will call Grand Lake, which occupied the southeast quarter of Utah, parts of northeastern Arizona, as well of small parts of Colorado and New Mexico. It stood at an elevation of 5,700 feet above our present sea level. Grand Lake spilled over and quickly eroded its natural dam 22 miles southwest of what is now Page, Arizona. In doing so, the western boundary of former Hopi Lake (elevation 5,950 feet) was eroded, releasing the waters that occupied the present valley of the Little Colorado River. In just a few days, more water was released over northern Arizona than is in all the Great Lakes combined.

Page 83:

Marble Canyon was eroded by the waters of Grand Lake, while the Grand Canyon was eroded by the waters of both Grand and Hopi Lakes. The boundaries of both Hopi and Grand Lakes have been recently identified by a number of their geological and topological features. Hopi Lake has been reported on previously.** The catastrophic dumping of Grand Lake took place through what is now the gap between Echo Cliffs and Vermillion Cliffs. Before the rapid erosion of this natural dam, those two cliffs were a single face of a block faulted mountain. The release of these vast waters first eroded hundreds of meters of relatively soft Mesozoic sediments off of northern Arizona. Once completed, the downcutting through the relatively hard Kaibab limestone began. As it proceeded, more water, with increasing hydrodynamic head, was released from the water saturated sediments flanking the canyon. Subsurface flow, mass wasting, and slumping were extreme. The weight of material removed from northern Arizona produced isostatic uplifts that account for the "Barbed" Canyons,*** the Kaibab Plateau, much faulting, and some volcanism. The timing of this event is uncertain. Perhaps it took place a century or two after the flood.

**R.B. Scarborough, *Cenozoic Erosion and Sedimentation in Arizona*, Arizona Bureau of Geology and Mineral Technology, 16 November 1984.

***In most cases, side streams enter their main streams at acute angles. However, the drainage through the "barbed" canyons enter the Colorado River at obtuse angles. These canyons are called "barbed" because on a map their backward orientation gives them the appearance of barbed wire. Except for an occasional cloudburst directly overhead, there is essentially no drainage through these giant canyons. So what cut them, and why are they backwards? The answer lies in the northward dip of the land shortly after the vast weight of sediments were suddenly removed to the south by the dumping of Grand and Hopi Lakes. The drainage pattern was reversed for the surface drainage and the waters spilling out of Echo and Vermillion Cliffs and elsewhere.

Since August 1989.

Austin acknowledged in a phone call that he purchased a copy of my book while visiting friends in St. Paul, MN. This occurred several weeks after it was published in late August 1989.

The portion of the *1990 ICR Guidebook* which dealt with the formation of the Grand Canyon suddenly became very definite and more detailed. An 11-page section in the larger *1989 Guidebook* entitled "Erosion of the Grand Canyon–A Geologist's Personal Reflections," became a 25-page chapter entitled "How Was the Grand Canyon Eroded" in the smaller *1990 Guidebook*. "Reflections" became "How It Happened." A two-page subsection entitled "The Catastrophic Drainage Theory" in the *1989 Guidebook* became three sections, totaling 11 pages. Those section titles were: "The Breached Dam Theory," "Evidences for the Breached Dam," and "How the Breach Occurred." Most significantly, the 1990 edition had a map (page 76) very similar to the one I published above, even including for the first time in an ICR book the names Hopi Lake and Grand Lake—unreferenced.

A lady who took the April 28 - May 6, 1990 ICR tour sent me her book several months later. I scanned it, saw the map of Grand and Hopi Lakes, and guessed that Austin "lifted" my explanation. I was not shocked, because I had seen, in the *1988 and 1990 Guidebooks*, many examples of artwork that Austin had "lifted" from other authors. Austin and I had read many of the same reports. I spent less than five minutes looking over the *1990 Guidebook*. It was not until June 16, 1993, when I was writing Austin, that I read the relevant section.

More Plagiarism.

Cutting out a copyrighted figure, pasting it in your book, and then copyrighting your book is a copyright infringement (plagiarism) and illegal. Simply mentioning the originator's name, as Austin sometimes did, is not a copyright release. How ICR intended to distribute that copyrighted book is irrelevant; ICR copyrighted artwork that was not theirs.

For many years, I have been aware of another likely case of plagiarism by ICR, which I brought to Dr. Henry Morris' attention on June 18, 1993. His complete response is as follows:

> With reference to the Slusher book, this is the very first time I have heard of any "plagiarism" in the book. The example you cited seems--superficially at least--to be a fairly standard mathematical derivation. I doubt whether Professor Stacey would call it plagiarism. In any case, this is the first time anyone has mentioned it. As you know, Harold Slusher left ICR about eight years ago and we have had very little contact with him since. The only reason we still list a few of his monographs is because the original printings have not been exhausted. We have never planned to reprint any of them. In view of your complaint, we will possibly delete this particular book from our next catalog, although much of the information in it is still worth while.

I was sorry that Morris did not see this as a likely case of plagiarism, and that he viewed it as a complaint. I had hoped he would appreciate being told of a possible problem and would consider removing the book from his inventory. Since Morris did not see this as plagiarism, the relevant pages are at Attachment 3 for the reader to decide.

In March 1991, I wrote Morris a six-page letter listing inaccurate writings by him in 1984 about which I had first-hand knowledge. Those widely distributed writings were harmful to my ministry. They were also a factor in my taking steps to close our organization in 1985. Those steps involved a move from Chicago to Phoenix. In that letter, I also suggested to Morris that we discuss other matters of accuracy in face-to-face meetings. He ignored my offer. Had he accepted, these subjects (and more) would have been brought privately to his attention in 1991.

Conclusions.

Newberry (1861) and Blackwelder (1934) were the first two people to propose that impounded lakes suddenly spilled out and eroded canyons along the Colorado River. In 1984, Austin wrote of similarities between the Grand Canyon and a 100-foot-deep canyon at Mount St. Helens, which formed as a result of a breached dam. In December 1986, Holroyd was probably the first person to show where a lake may have been which might have spilled out through a fault and formed the Grand Canyon. Austin wrote in the *1988 and 1989 Guidebooks* that he was considering whether a lake east of the Grand Canyon could have breached the Kaibab Plateau to form the Grand Canyon. I began speaking nationally about the "Grand Lake Explanation" (GLE) on September 16, 1988. I published a brief summary of the GLE in August 1989, which Austin obtained weeks later. It specified how and where the breaching occurred, how the lake was filled, why so much water was released so quickly, and why the Kaibab Plateau formed after Grand, Hopi, and higher lakes dumped. Austin published in the *1990 Guidebook* a map, similar to mine, showing and naming, without reference, Grand Lake impounded behind Vermilion/Echo Cliffs.

For several years, I have tried to ignore vague claims that I had plagiarized Austin's work. Clearly, ignoring the matter would only make it worse. Dr. and Mrs. Block independently recall hearing such allegations from an angry Steve Austin. Surprisingly, Austin told me, in writing and on the phone, that he never felt that I had taken his ideas.

On the other hand, Austin has continually taken the artwork of many Grand Canyon researchers, placed them in ICR's *Guidebooks*, and then copyrighted those *Guidebooks*. He took credit for Holroyd's important ideas, which preceded mine by two years, and placed them in his "backdated" *1989 Guidebook*. Austin then says that "my conclusion preceded your by two years." Austin knew that Holroyd's drawing was based on 5577 feet. Why then did Austin say in the *1989 Guidebook* that the big lake (really three lakes) was at a 5700 foot elevation? I began using that unique, but perhaps incorrect, number in September 1988. What overriding need caused Austin in February 1989 to go to the trouble to add Holroyd's map to the *1988 Guidebook*, but nothing else of technical substance? Finally, Austin's breached dam ideas became very detailed and specific in the *1990 Guidebook*, which he published about five or six months after he acknowledges buying my book. Also disturbing is Henry Morris' minimizing another example of plagiarism and copyright infringement within ICR.

What lies behind these actions? Does ICR believe that it must be the source of new ideas concerning Creation and the Flood? Is there a "not-invented-here" attitude, a problem of pride or even arrogance? I cannot answer this. But Matthew 18:15-17 is clear. *Go first to your brother privately*. I did that on June 18th. Next, *if he does not listen to you, take one or two more witnesses*. This paper does that. It is a simple matter to admit a series of mistakes, apologize, correct the cause (whatever it is), and move on from there. The creation movement would greatly benefit.

Attachments: (Attachments 1 and 3 are not included in reproductions of this report, but were sent to Austin and Morris. They are available on request.)

1. Audio Tape of Radio Interview with Walter Brown, dated September 16, 1988
2. Map conceived and produced by Edmond W. Holroyd, III
3. Copies from books by Slusher and Stacey

REFERENCES and NOTES

1. Michael J. Oard, "Comments on the Breached Dam Theory for the Formation of the Grand Canyon," *Creation Research Society Quarterly*, Vol. 30, No. 1, June 1993, pp. 39-46.

2. Emmett L. Williams, John R. Meyer, and Glen W. Wolfrom, "Erosion of the Grand Canyon of the Colorado River, Part III — Review of the Possible Formation of Basins and Lakes on Colorado Plateau and Different Climatic Conditions in the Past." *Creation Research Society Quarterly*, Vol. 29, No. 1, June 1993, pp. 19-21.

3. Walter T. Brown, Jr. *"In the Beginning . . ."* (Phoenix, Arizona: Center for Scientific Creation, 1989), pp. 58-83.

4. Steven A. Austin, "Rapid Erosion at Mount St. Helens," *Origins*, Vol. 11, No. 2, 1984, pp. 90-98.

5. Anyone interested should study the topic of "A Beam on an Elastic Foundation" in J. P. Den Hartog, *Advanced Strength of Materials* (New York: McGraw-Hill book Company, Inc., 1952), pp. 258-264.

6. See for example: William R. Corliss, *Unknown Earth* (Glen Arm, Maryland: The Sourcebook Project, 1960), pp. 627-628. Also see Brown, pp. 72-73.

7. Richard J. Chorley, et al., *The History of the Study of Landforms or the Development of Geomorphology* (London: Methuen & Co. Ltd., 1964), Vol. 1, p. 504.

8. Williams, et al., p. 19.

9. J Harlen Bretz, "The Lake Missoula Floods and the Channeled Scabland," Vol. 77, No. 5, September 1969, pp. 503-543.

10. Eliot Blackwelder, "Origin of the Colorado River," *Bulletin of the Geological Society of America*, Vol. 45, 30 June 1934, pp. 551-566.

11. Edmond W. Holroyd, III, "Missing Talus," *Creation Research Society Quarterly*, Vol. 24, June 1987, pp. 15-16.

12. Edmond, W. Holroyd, III, "Missing Talus on the Colorado Plateau," *Proceedings of the Second International Conference on Creationism*, Vol. 2 (Pittsburgh, Pennsylvania: Creation Science Fellowship, Inc., 1990), pp. 115-124.

13. Ibid., p. 126.

14. Howel Williams, "Pliocene Volcanoes of the Navajo-Hopi Country," *Bulletin of the Geological Society of America*," Vol. 47, 31 January 1936, p. 117.

15. Holroyd wrote me on June 26th 1993. In his letter he quoted an entire letter that Austin sent Holroyd on January 23, 1989:

> Dear Ed:
>
> The revised edition of our Grand Canyon Guidebook will include a revised section on erosion of Grand Canyon. I propose to include the enclosed illustration (drafted by our artist later) concerning the lake which would have formed behind the Kaibab Upwarp.
>
> The lake level shown is the 1700 meter level which your computer plotted. I drew this roughly from the photocopy I made of your color photo which you supplied (and I returned) with your letter of February 26, 1987.
>
> You mentioned that you could not release the photo because of government research support. Could I publish my sketch of the lake? Should I acknowledge you as the source? My thought is to leave the source unacknowledged if o.k. with you.
>
> Sincerely,
> \Steve Austin\

Holroyd added: Austin's "sketch was a bit crude. So I hand traced my color print and sent it to him on 2 February 1989. I said he could refer to my 1987 CRSQ note for a reference or list it as personal communication."

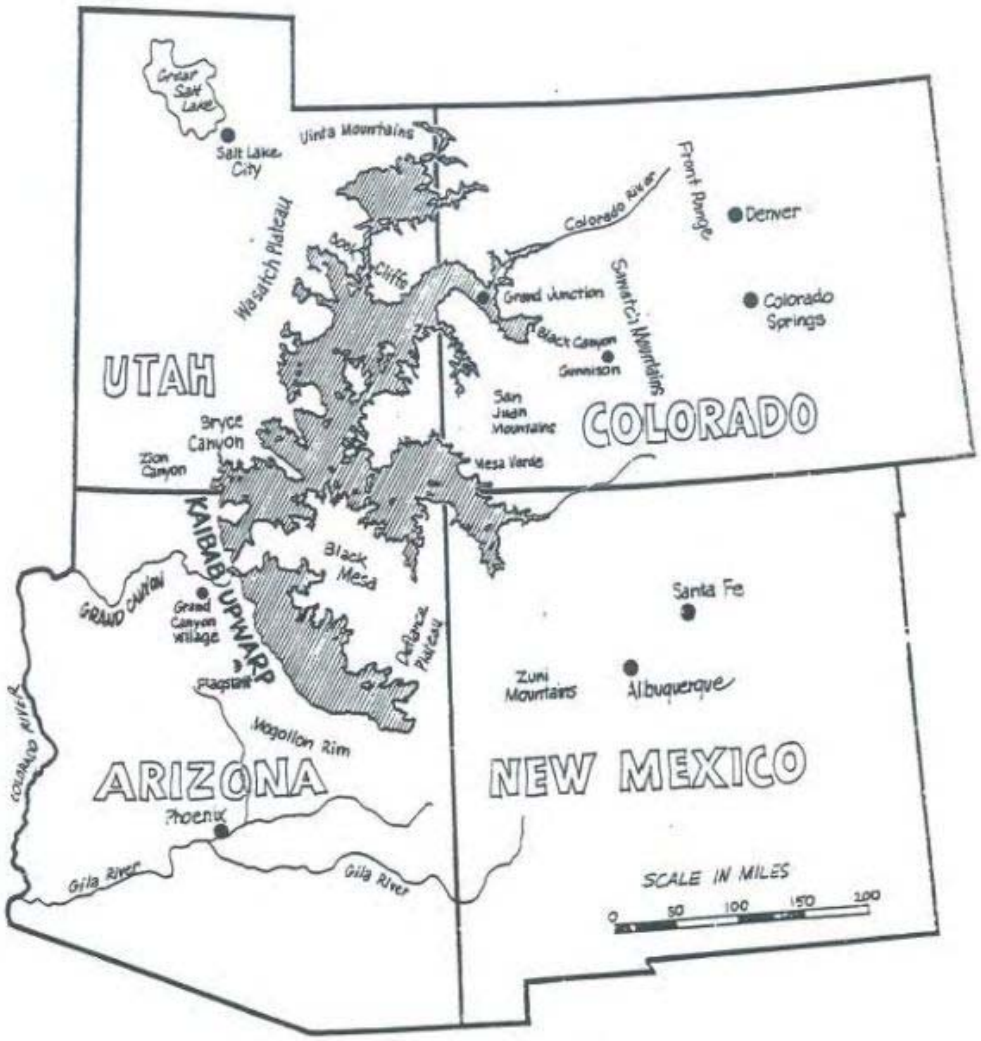
Notice, Austin was aware on January 23, 1989, that Holroyd used the 1700 meter (5577 foot) contour line to define his lake. However, under the map (Attachment 2), Austin wrote that the lake was at 5700 feet elevation.

16. For example, see Brown, p. 75.

17. Actually, I determined in 1988 that it is 5610 feet. That is the elevation of the saddle on Highway 89 in southern Utah where water would spill from the dammed lake. See the U. S. Geological Survey topographic map "Telegraph Flat, Utah—Arizona" 1:24,000. Arriving at the correct number was so important that I used a calibrated altimeter to get better accuracy than the 40-foot contour interval of that map.

18. Personal letter from Dr. Edmond W. Holroyd, III, dated June 26, 1993.

19. See the indicated pages in Brown, pp. 58-83.



A computer was asked to draw the shoreline of the lake which would form behind the Kaibab Upwarp if the Grand Canyon were blocked at the 5,700-foot elevation. The lake which would form is shown above. It would contain the water of three Great Lakes. This computer-generated lake approximates the outline of the ancient lake which breached its dam to form Grand Canyon.

Attachment 2

from ICR Grand Canyon Tour Guidebook 1989

Gemini XI photograph of the Gulf of Aden and the Red Sea by NASA astronauts Charles Conrad and Richard F. Gordon. This is one of the areas of particular interest in the theory of sea-floor spreading. A line of earthquake epicenters (see Figs. 4.1 and 7.4) extends from the ridge system in the Indian Ocean up the middle of the Gulf of Aden and into the Red Sea and is presumed to mark the axis of a new ridge, along which mantle material is rising and pushing Africa and Asia apart. Photograph courtesy of the National Aeronautics and Space Administration, Washington, D.C.

See pages 14-16.

Physics of the Earth

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PREFACE

... Obviously there are no well qualified students of the Earth, and all of us, in different degrees, dig our own small specialised holes and sit in them."

BULLARD, 1960, p. 92.

The first purpose of this book is to bring the fundamental problems in solid-earth geophysics to the attention of graduate and advanced undergraduate students of physics. The physical study of the Earth has a natural fascination, but for the physicist who has no previous contact with the Earth sciences there is a wide range of new concepts. Mathematical developments are here simplified or relegated to appendices, so that they do not obscure the physical arguments; I hope that this has made most of the text digestible to students of geology and related sciences. I have also aimed to extend its usefulness by a careful selection of references from the now vast literature.

Most geophysical effects are not accessible to scientific manipulation and they are often complex. The materials concerned are neither pure nor homogeneous and exact analysis is often out of the question. In these circumstances vague suggestions become hypotheses and hypotheses are called theories. Improbable theories abound and are difficult to dispose of convincingly, if only because someone can find another, possibly irrelevant factor which has not previously been considered. Geologists are aware of this situation and allow for it. A physicist meeting it for the first time may be disillusioned and so needs to be warned. In many problems rigorous analysis does not take us very far; numerous loose ends are tied together only by intriguing speculations. Our task is to sift the plausible from the improbable and to devise tests to distinguish them. Order-of-magnitude arguments play an important part, and a feeling for the magnitudes of geophysical quantities is necessary to a sense of relevance. In particular, calculation of the energies involved in various processes often allows us to narrow the range of possible ultimate causes.

The field is so wide that a selection of topics, chosen with some bias of personal interest, is inevitable. My selection is based partly upon an attempt to predict the topics which will increase in relative importance. Paleomagnetism is presented as a central theme. I am impressed by the revolution in geophysical thinking which it has caused by establishing continental drift as an

.4 The Poynting-Robertson Effect

Solar radiation has an important influence on the orbits of small particles whose ratio of surface area to mass is large. Its effects on the meteor streams have been studied in detail and a historical and physical discussion is given by Lovell (1954). Particles up to about 1C cm diameter are affected on a time scale of 10^9 years.

It is convenient to distinguish three effects of solar radiation pressure, although they are not really independent. First, there is a simple outward force from the Sun. For particles with diameters of a few thousand Angstroms or less this force may exceed the gravitational attraction of the Sun and blow them out of the solar system. This problem is complicated by the fact that the critical particle size is comparable to the wavelength of the radiation and the effective optical cross section is not the simple physical cross section. We are concerned here with much larger particles. Second, the solar radiation received by a particle is Doppler-shifted to cause an increase in radiation pressure if the particle is approaching the Sun and a decrease if it is receding; elliptical orbits are thus reduced to nearly circular orbits. Third, the angular momentum of an orbiting particle is progressively destroyed by the fact that it receives solar radiation, which has only a radial momentum from the Sun (neglecting the solar rotation), and reradiates this energy with a forward momentum corresponding to its own motion about the Sun. This is the essential feature of the Poynting-Robertson effect, which is most conveniently analyzed as a problem in relativity.

We consider the special case of a spherical particle of mass m and diameter d in a circular orbit at radius r. Its orbital velocity is

$$v = \left(\frac{GM}{r}\right)^{1/2} \tag{1.6}$$

M is the mass of the Sun and G the gravitational constant, so that the total orbital energy is

$$E = -\frac{GMm}{r} + \frac{1}{2}mv^2 = -\frac{GMm}{2r} \tag{1.7}$$

It is convenient to consider separately the processes of absorption and reradiation of the energy.

In time dt the particle receives energy $d\epsilon$ as solar radiation, and this causes an increase in mass

$$dm = \frac{d\epsilon}{c^2} \tag{1.8}$$

c being the velocity of light. But since this radiation traveled radially from the Sun it carried no orbital angular momentum and the total angular momentum of the particle is conserved, so that

$$m\,d(vr) = -vr\,dm = -\frac{v}{c^2}r\,d\epsilon \tag{1.9}$$

The particle then reradiates the energy $d\epsilon$, but it does so isotropically in its own frame of reference and this process involves no reaction on the particle. The orbital velocity is therefore conserved in the radiation process and since the mass dm is lost, a net loss of angular momentum by $vrdm$ occurs. This angular momentum is carried away by the radiation, which, when viewed in the stationary reference frame of the Sun, is seen to be Doppler-shifted; the energy and momentum projected forward from the particle exceed the energy and momentum radiated backward.

The rate of loss of orbital angular momentum may be equated to a retarding torque L:

$$L = m\frac{d(vr)}{dt} = -\frac{v}{c^2}r\frac{d\epsilon}{dt} \tag{1.10}$$

so that

$$\frac{dE}{dt} = L\frac{v}{r} = -\frac{v^2}{c^2}\frac{d\epsilon}{dt} \tag{1.11}$$

Now $d\epsilon/dt$ is the rate at which the particle receives solar radiation and is given by

$$\frac{d\epsilon}{dt} = S\left(\frac{r_E}{r}\right)^2 A \tag{1.12}$$

where S is the solar constant, the energy flux through unit area at the distance r_E of the Earth's orbit, 1.39×10^6 ergs cm^{-2} sec^{-1} (1400 wm^{-2}), and $A = (\pi/4)\,d^2$ is the cross-sectional area of the particle. Thus by differentiating Eq. (1.7) and equating to Eq. (1.11) with the substitution of Eq. (1.12) we obtain

$$\frac{GMm}{2r^2}\frac{dr}{dt} = -\frac{v^2}{c^2}S\left(\frac{r_E}{r}\right)^2 A \tag{1.13}$$

and since v is given in terms of r by Eq. (1.6), we obtain the differential equation for r:

$$r\frac{dr}{dt} = -\frac{2Sr_E^2 A}{mc^2} \tag{1.14}$$

Integrating from the initial condition, $r = r_0$ at $t = 0$:

$$\frac{r_0^2 - r^2}{r_E^2} = \frac{4SA}{mc^2}t \tag{1.15}$$

which, for a spherical particle of density ρ, becomes

$$\left(\frac{r_0}{r_E}\right)^2 - \left(\frac{r}{r_E}\right)^2 = \frac{6S}{d\rho c^2}\, t \qquad (1.16)$$

where (r/r_E) is the radius of a particle orbit, expressed in astronomical units (AU).

We are interested in the time taken by particles, of diameter d, originating in the asteroidal belt at $2.7\,r_E$, to reach the Earth's orbit, r_E. Assuming a particle density of 4 gm/cm^3 and d in centimeters, this is

$$t = 8.6 \times 10^7\, d \text{ years} \qquad (1.17)$$

A more complete analysis (Lovell, 1954, pp. 402–409) shows that a particle in an elliptical orbit is first reduced to a nearly circular orbit, just inside its initial perihelion distance. Since this process also depends upon the Doppler shift of radiation due to motion of the particle relative to the Sun, the time required is similar to that for the spiraling effect.

The Poynting-Robertson effect thus ensures that any small particles in the common meteoroid range (less than 1 cm diameter), which originated in the asteroidal belt about 10^8 years ago, would have passed the Earth's orbit and spiraled into the Sun. McKinley (1961, pp. 169–171) has pointed out that very few meteors appear to be due to particles having the density of stone or rock. They are envisaged as loose, dusty aggregates, similar to the supposed structures of comets and quite different from the meteorites. The relative rarity of very small meteorites is consistent with the conclusion that they must be products of recent asteroidal collisions. Further, we can see that if a primary asteroidal fragmentation had occurred very early in the history of the solar system, say 4×10^9 years ago, then all primary fragments smaller than 50 cm would have spiraled into the Sun and the terrestrial collection would be strongly biased toward the shorter cosmic ray exposures of more recent, secondary fragmentations. Thus the currently available exposure age data do not permit us to decide whether the meteorites originated in one or two fairly large or many smaller parent bodies. Although the complexity of the chemical evidence appears to demand at least four parent bodies, semi-independent physical evidence is very desirable.

1.5 Compositions of the Terrestrial Planets

In spite of their uncertain mechanical histories, meteorites have had a profound influence upon our ideas about the composition, internal structure, and history of the Earth. They provide us with samples of the compositions of the terrestrial planets which are far more representative of the planets as as whole than are the rocks to which we have access near the surface of the Earth. Chemical considerations now dominate the discussion of the nature and

origin of the Earth. Important reviews, although with somewhat divergent views, are given by Urey (1952, 1957, 1963) and Ringwood (1966a); MacDonald (1963a) has reviewed the physical aspects of studies of internal constitutions of the terrestrial planets.

Meteorite compositions are in satisfactory accord with spectroscopic estimates of the solar abundances of nonvolatile elements. The dominance of Si, Mg, and Fe strongly indicates that all of the terrestrial planets are composed essentially of magnesian silicates and iron, either as metal or oxide. The average density of the Earth (Table 1.1) and its internal structure deduced from seismology (Chapter 4) agree well with the presumption that the Earth has a liquid iron core, of uncompressed density $\rho_0 = 7$ gm cm^{-3}, and a solid silicate mantle with $\rho_0 = 3.3$ gm cm^{-3}. The proportions are estimated from the measured radius of the core. In the same way we can interpret the average densities of the other terrestrial planets in terms of iron cores and silicate mantles in different proportions, although we have no direct estimates of the core sizes. Mercury, whose uncompressed density is substantially greater than that of the Earth, must have a larger core in proportion to its total volume. At the other extreme, the low density of the Moon leads us to conclude that it has virtually no core.

Venus is very similar to the Earth in both size and density and is presumed to be essentially similar internally, but if we assign to Mars an iron core of radius calculated to give the observed mean density with a silicate mantle of $\rho_0 = 3.3$ gm cm^{-3}, then we run into difficulty. From the motions of its satellites the mass of Mars is well determined. The moment of inertia is also estimated, assuming approximate hydrostatic equilibrium for the surface, as in the calculations given for the Earth in Section 2.1 (Wilkins, 1967; Runcorn, 1967b)* and is found to correspond much more nearly to uniform density than in the case of the Earth. Allowing for uncertainty of the radius, the core can be no more than 10% of the total mass, and is probably substantially less; moreover, a much higher density must be assigned to the mantle than in the case of the Earth. This observation gives strong support to Ringwood's (1966a, 1966c) theory of planetary evolution, which leads to different oxidation states for the terrestrial planets, so that in Mars virtually all of the iron has remained oxidized and therefore has not separated from the silicates. According to Ringwood the overall Fe/Si ratio in Mars is approximately the same as that in the Earth, the iron occurring as oxide, which has a density of 5.2 gm cm^{-3}. When added to silicate of $\rho_0 = 3.3$ gm cm^{-3}, it brings the uncompressed silicate density up to $\rho_0 = 3.7$ gm cm^{-3}, to which only a small core need be added to give the observed Martian density. In view of the high

* Disagreement between the observed surface ellipticity and that expected from the dynamical ellipticity raises doubt about the assumption of equilibrium, but this is not sufficient to invalidate the conclusion drawn here.