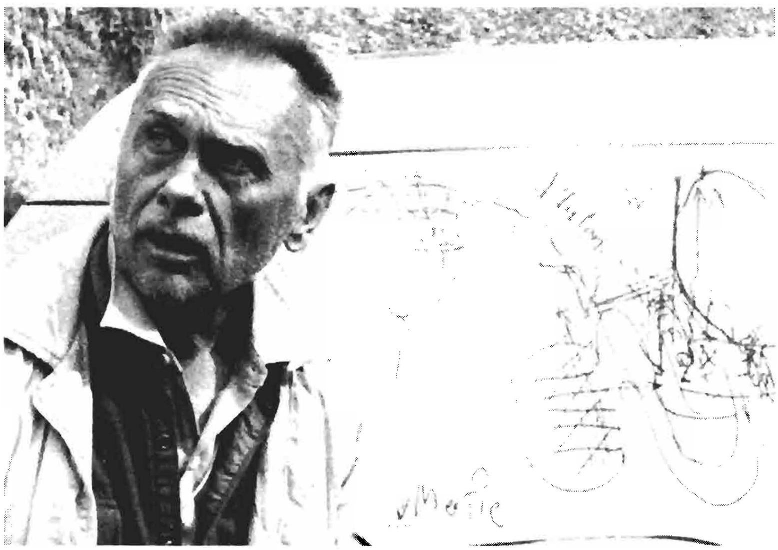
ALBERT EDWARD JOHN ENGEL
1916 – 1995
BY ROBERT J. STERN

3

Revolution was in the air in the mid-1960s. This was certainly true for American society and politics. Among the sciences, only the earth sciences experienced a comparable paroxysm. At about the same time that American culture came loose from its post-WWII moorings, the continents seemingly began to move and the focus of research excitement shifted to the ocean basins. Harry Hess of Princeton University and Robert Dietz of the Navy Electronics Laboratory in San Diego, independently portended the revolution in the way we see Earth: the key is that the continents drift because Earth's upper mantle is convecting. Mantle convection led to the formation of new oceanic crust at mid-ocean ridges—"spreading seafloor theory," Dietz called it. North American land geologists had long ridiculed the notion championed early in the century by South Africa's Alex du Toit and by that mad German meteorologist Alfred Wegener, that the continents moved relative to each other. A new perspective emerged from the amazing advances in marine technology spawned by naval



Engel expounding on geologic complexities on the east flank of the Peninsular Ranges batholith. As can be seen here, Al often taped up a piece of butcher paper over one of the side rear windows of the field trip van and then drew it as he saw it with black, felt-tip marker. Spring field trip, 1975 or 1976.

operations during WWII and by tensions between the U.S. and U.S.S.R. Improved navigation and sonar; sonobuoys; and magnetometers were tools that made marine geophysics blossom. These technologies, mainly designed to combat enemy submarines, were easy to adapt to study of the seafloor itself. After 1955 we had a much better sketch of what the seafloor looked like, especially over large portions of the North Atlantic and Western Pacific. From the early 1960s when the essays of Hess and Dietz were published, the action clearly lay in the oceans, the realm of 'MG&G': marine geology and geophysics. Something different and important was occurring on the ocean floor, particularly along the 60,000 km of seismically active mid-ocean ridges, and marine geologists and geophysicists worked hard to get to the bottom of it.

Results came in fast, especially from geophysicists. Scientists had been puzzled for some time by the zebra-like stripes of positive and negative magnetization, discovered by Scripps's Ronald Mason and Art Raff in 1955-1956, which were often symmetric around mid-ocean ridges. In 1963, Cambridge's Fred Vine and Drummond Matthews (and, independently, Canada's Lawerence Morley) proposed that this pattern resulted when lava erupted at different times along the crest of mid-ocean ridges cooled, freezing magnetic particles along then present orientations of Earth's magnetic field. They suggested that these different patterns of magnetic anomalies preserve a record of seafloor construction, much as tree rings tell about the growth of a tree.

But what was the seafloor made of? Russ Raitt and other seagoing geophysicists had already shown that the crust beneath the oceans and the continents was distinct. Oceanic crust was a tenth as thick as continental crust and compositionally distinct, but the compositional differences were hazily defined, at best. Raitt's seismic refraction studies indicated that oceanic crust allowed sound waves to travel faster than did continental crust. Oceanic crustal layers had seismic velocities similar to basalt and its slowly cooled, plutonic equivalent, gabbro, but these velocities were also similar to those of several other kinds of igneous and metamorphic rocks, including partially serpentinized peridotite. We knew that peridotite—the characteristic rock of Earth's upper mantle—lay beneath the oceanic crust, because Scripps's Bob Fisher had dredged it several places in the deep trenches of the Western Pacific. Hess thought that the oceanic crust was made of serpentinite, which could form when mantle peridotite interacts with seawater. Raitt's results indicated that sound waves moved through oceanic crust too quickly for it to be composed of pure serpentinite, but it could contain a lot. Geophysicists could reveal much about the oceanic crust, but studying it with sound alone left many questions.

The only way to know the oceanic crust for sure was to sample it directly. To really know requires drilling and coring it all the way down to the Mohorovicic Discontinuity (Moho, for short) the boundary between the crust and underlying mantle. This would not only allow the composition to be determined directly, it would also allow its structure to be examined. In 1957, Roger Revelle and Walter Munk of Scripps, along with Harry Hess proposed 'Project Mohole' to do this. Project Mohole was to include three phases, the first consisting of an experimental drilling program, the second consisting of an intermediate vessel program, and the third consisting of the final drilling to the Mohorovicic Discontinuity. After oceangoing trials off La Jolla, Phase I began in 1961 with drilling five holes in 11,000 feet of water west of Guadalupe Island, Mexico. The upper part of oceanic crust was cored for the first time, and it was basalt. Drilling to the Moho must have seemed within the project's grasp in those heady days of 1961 and 1962, the mantle being only three or four miles below the seafloor, not much more distance than a noon jog on the beach. You wouldn't think it's hard to do this, but it is. Even today, the deepest hole in oceanic crust, DSDP 504B, reaches only 2 km beneath the seafloor. Various committee conundrums and fiscal fiascoes stymied the project after the initial success, and it was laid to rest in 1966. Project Mohole was an ambitious failure but nevertheless morphed into the spectacularly successful Deep Sea Drilling and Ocean Drilling Projects. Despite its scientific importance and incredible technological advances in drilling at sea, the goal of drilling all the way through the oceanic crust still has not been accomplished. Maybe this goal will be reached by the new International Ocean Drilling Project, which should begin in 2003.

Another way to know oceanic crust is to study it where it has been stranded on land, where it is called an ophiolite. Ophiolites are distinctive assemblages of deep-sea sediments, pillowed basalts, sheeted dikes, gabbro, and serpentinized mantle that are thrust up on land when continents collide. Collision destroys the intervening ocean basin but sometimes leaves an ophiolitic scrap or two. Like Moholes, ophiolites allow crustal structure and composition to be examined directly. A lot has been inferred about oceanic crust from studying ophiolites, but we now know that most ophiolites did not form at true mid-ocean ridges like the East Pacific Rise or Mid-Atlantic Ridge. Most ophiolites form at juvenile convergent margins (intra-oceanic island arcs, like the Marianas) and while this oceanic crust is in many ways similar to that produced at mid-ocean ridges, there are differences. Now we know that there is more than one type of oceanic crust. One kind, formed at convergent plate boundaries, makes up a small portion of the oceanic crust but is disproportionately preserved as ophiolite. The other kind of oceanic crust forms at mid-ocean ridges, makes up the vast bulk of the seafloor, but is rarely preserved as ophiolite. These distinctions were not imagined in the 1960s.

The simplest, easiest, and cheapest way to know what the oceanic crust is made of is to recover pieces of it from along the mid-ocean ridge. This is where the oceanic crust forms, and however the baby seafloor reveals itself there must, to a first approximation, represent the entire crust. On the other hand, samples recovered by dredge provide no definitive information about crustal structure, but marine geophysics and the ophiolite analogue could fill in this gap. There was much to be learned by directly sampling the mid-ocean ridges.

There long had been a number of samplings of the mid-ocean ridges by marine geologists, and all indicated the importance of basalt. Geochemists knew that there are many kinds of basalt: alkali basalt, olivine basalt, high-alumina basalt, and tholeiite, to name a few. We now know that basalt is not limited to this planet. Basalts were collected on the Moon during the Apollo program, and fragments of Martian basalt blasted off that planet have crashed on Earth. Russian landers on Venus lasted long enough on that surficial hell to analyze a few rocks—basaltic in composition—consistent with results of the Magellan radar mapping mission, which suggested that basalt flows cover the planet. Some basaltic meteorites—better known as eucrites—are derived from the inner asteroid belt. Basalts are common because they are produced when mantle peridotite melts, and clearly Moon, Mars, Venus, asteroids, and Earth all have mantles that have melted. In a sense, basalts are probes of mantle composition and melt processes. That the oceanic crust was largely composed of basalt was reasonable, but this was only part of the story. If igneous oceanic crust was made of basalt and gabbro, what kind of basalt was it?

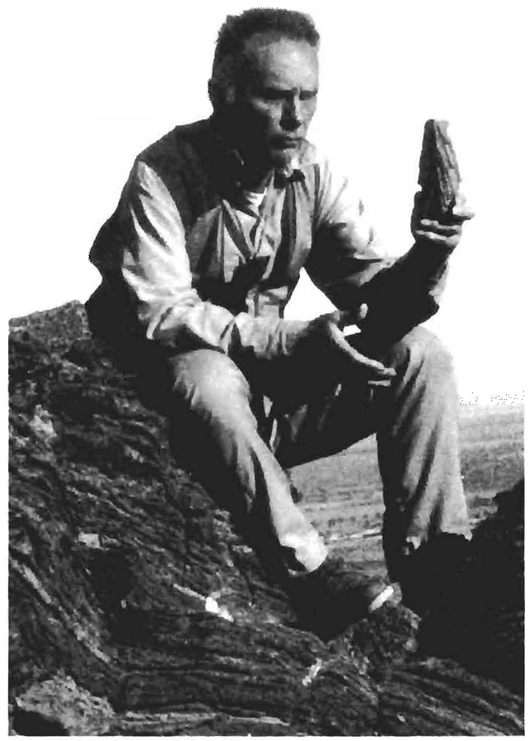
Al Engel was uniquely well suited to answer the question, even though he had published nothing about basalts nor marine geology prior to his arrival at Scripps in the late 1950s. Engel reached scientific maturity in the 1940s and 1950s, when the field of marine geology was as new, amorphous, and speculative as planetary geology. As a doctoral candidate he studied at Princeton under Arthur Buddington. Al and his wife Celeste worked together, to extend Buddington's pioneering studies of metamorphic rocks in the Adirondack mountains of New York. The Engels contributed to the raging controversy of the 1950s—whether granites were truly igneous rocks or formed as a result of infiltration of K, Na, Si, and other cations into rocks of the deep crust, at high pressures and temperatures. One camp argued that granites were never molten but formed when metamorphic rocks deep in the crust were infiltrated by potassium-bearing fluids and changed—metasomatized—into granite. The other camp argued that granites are igneous rocks, that is, they were once molten. In retrospect, it is hard to understand what all the fuss was about, but fuss there was plenty. Al and Celeste enthusiastically entered the fray. The Adirondacks were a great place to address the controversy, and their work demonstrated just how much K, Rb, Ba, and related elements in the surrounding metamorphic rocks had fled as a result of the intrusion of a granite pluton. Their careful field and geochemical studies of Adirondack metamorphic rocks were masterpieces of the time.

Most scientists would loathe to venture into a field as different from their own as the composition of the seafloor would have been to Al Engel, but he was blessed with a remarkably contrarian personality and a profound love for learning about the planet. Al was a Missourian, and a truer representative of the "Show Me State" cannot be imagined. His mercurial temperament, when combined with the skills and tact of Celeste, who was widely acknowledged as one of the best chemical analysts in the U.S. Geological Survey, resulted in a team that was technically and temperamentally well prepared for the task at hand. These advantages were multiplied because they were at Scripps, with ships and men who knew how to get rocks from the bottom of the ocean, and where Director Revelle encouraged the faculty to 'think big.'

Figuring out what the oceanic crust was made of meshed nicely with Al's evolving career. His research interests changed from practical to academic and from local geology successively to that of continental North America and then to that of the oceans and other continents. He spent the Second World War working for the U.S. Geological Survey, looking first for optical-grade quartz crystals that could be used for radio diodes and then assessing talc mines in New York, talc being needed for marking welding spots, vulcanizing rubber, and as matrix for naval paint. During the late 1940s and almost all of the 1950s, he was a geology faculty member at the California Institute of Technology in Pasadena, where he and Celeste carried out most of their meticulous studies of Adirondack metamorphism. Robert Sharp, who was chairman of the Caltech Geology Division while Engel was on the faculty, says that Al was "... one of the best members of our faculty .... He was thoughtful, original, imaginative, and innovative in discussions of where our division should go." Sharp says that Al "... more than anyone else was responsible for getting us into geochemistry." Sharp valued Al's opinion, although "... Al could be unnecessarily rough and blunt in discussions with people ..." and that "Al had as many enemies as he had friends." Sharp used Al as a sounding board, recalling "I often ran my own ideas past Al. If they survived his caustic analysis, I often felt they were worth pursuing. He was awfully good at recognizing phonies."

Al continued to galvanize, polarize, and otherwise electrify after he arrived at Scripps as a full professor in 1958. One Scripps faculty member who knew Al well observed: "Let's face it, Al had few collaborators, many adversaries, and quite a few like (another Scripps scientist) who simply loathed him and made no bones about it." This faculty member went on to say "My first 20 years with him were no picnic but I must say that the last few times I saw him he was a different guy, and we got along well."

Al had a similar effect on students he supervised at Scripps during the early years. Norm Banks, who was Al's student during the late 1960s, recalls a man who was a frustration in the office but an inspiration in the field. "... I remember a seldom seen figure who was ... hard to trap long enough to get feedback .... In the field, however, he was a different and totally geologic animal. He lived and breathed rocks and could bring an outcrop alive with his enthusiasm and knowledge. Over the campfire, he could describe long-since-visited rocks in spellbinding fashion, and he could hold your attention all night with spin-off stories, ideas, experiences, and creative social solutions that (he) promised to enact after retirement. The one I remember most vividly was his planned war on roadside (signs) ... buy 600 chainsaws ... crisscross the country to all motorcycle gangs therein ... give each a chain saw and 500-mile route map and $250 plus a promise of another $750 when they arrived at route's end with all signs between leveled. Done in one night, he figured this would inflict so much monetary damage to the advertising industry that it would take decades to recover." Banks also recalls that "Al was also one of the most motivating classroom and lab instructors at Scripps, again because of his enthusiasm for geology ..."



Engel contemplating deformed marble in Anza-Borrego State Park, CA. This was a favorite locality for teaching field mapping techniques to students. Spring, 1975.

I knew Al during 1974 to 1979, when he was in his late 50s and early 60s. His was the dominant laugh on the second floor of Ritter Hall, and his long, braying 'har-har-har' announced that he had arrived, had donned his lab coat, and was seated at his desk, ready for visitors to join him in his office. Al had a remarkable physical appearance to go along with his energetic and mischievous personality, startling pale blue eyes, brush-like white hair, and the lean body of a life-long field geologist. I frequently enjoyed listening to him cuss and discuss for hours. Geology was his favorite topic, but he had an opinion on almost everything.

There is no doubt in my mind that Al's best teaching was in the field, either in the geologic mapping class he taught to UCSD undergraduates on Saturdays at Anza Borrego, or on the spring field trips he organized for the Scripps graduate students. In 1976 he went with Tim Dixon and me to get us started on Ph.D. projects in the Precambrian of Egypt. He detested the time that he spent in Cairo but delighted in time spent in the pristine desert. I made only two mistakes with him on the two trips we took to Egypt. Once I shared a tent with him, but he snored so loudly that in the middle of the night I moved my sleeping bag out of the tent and some distance away on to the desert floor. Another time, I paid a price for my teasing. Al was a very selective eater in third-world countries, and in Egypt preferred a diet of local bread baked hard, peanut butter, and delicious Egyptian oranges. Peanut butter was not easy to find outside of Cairo in the mid-1970s, and I poked fun at this preference. I hadn't anticipated that after several lunches of sardines and tuna, Al's peanut butter would start to look good. One lunch I broke and asked Al if I could have the little bit left in a jar. "You want this?" he asked. He smiled, arched an eyebrow, and held out the jar, ready to pounce. Just as I reached for the jar, he smashed it down on the rocks next to him.

In 1977, Al took Tim and me to Saudi Arabia. This was just across the Red Sea from the areas that we were studying in Egypt, so the Precambrian rocks were very similar. The U.S. Geological Survey was doing a lot of work there, and Al arranged for a couple of field trips. First, Al was expected to give a lecture at King Abdul Aziz University. The audience was mostly Saudi men in white robes, plus a few U.S.G.S. scientists. Al went through the slides but the audience wasn't with him. Then he went to the blackboard and drew his signature diagram, a plot of potassium versus time. Al used this to hammer home the point that rocks of the continents evolve from primitive, low-potassium suites to evolved, high-potassium suites over a number of time scales: those corresponding to the growth of a volcano, a mountain range, or a continent. This diagram tended to show up in every lecture that he gave, and Tim and I knew it very well. It usually brings back audiences because it promises to explain just about everything. I guess Al could sense that even this wasn't working, and that a stronger shock was needed. Tim and I were stunned when he stood with his back to the blackboard, his right arm pointing to the diagram, and announced "This is my Koran!" He definitely had the full attention of the audience from that point on, but Tim and I were greatly relieved that no violence ensued from Al's insult.

It is not surprising that the Engels abandoned detailed studies of Adirondack metamorphism shortly after leaving Caltech and began to pursue the broader field of crustal evolution. Caltech had a reputation for detailed studies, whereas Scripps under Revelle's leadership had an unrivalled global perspective. Menard called Revelle "that matchless recruiter," and the director must have hired Engel to explain the record of Earth history preserved in the continents to the marine experts. "Keep the bastards honest," Al would say. Engel warned in his 1963 *Science* paper, that "The continents ... present a sea of data in which we are constantly in danger of drowning." The community at Scripps may have been startled and puzzled at the prospect of drowning on land, but Al gladly accepted the role of continental lifeguard. This is revealed in his role in a course at Scripps called "On the Origin and Evolution of Practically Everything." According to Jim Natland, who took the class, Harold Urey discussed the Moon, the Burbidges explained the 'Origin of the Universe,' Stanley Miller was in charge of the 'Origin of Life,' Jim Arnold handled the 'Origin of the Solar System,' Bill Menard dealt with 'Plate Tectonics of the Pacific,' and Engel held forth on the 'Origin of Continental Crust.' This course had disappeared by the time I arrived at Scripps, but what an education for the graduate students to hear the great scientists discuss the great questions! This must have been a hell of a course, one that Scripps should resurrect.

Engel and Spring field trip class at Dante's View, Death Valley, CA, in 1961. Photo courtesy of Kent Condie.

One can almost picture Al's mischievous glee: if Scripps wanted him to be in charge of explaining the continents, then it would be that much more fun to explain the oceans. In any case, that is what he and Celeste did. First, Al cemented his reputation as a leading expert on how continents form—crustal evolution, he called it—when he published his 1963 *Science* paper "Geologic Evolution of North America." He showed that the continental crust of North America grew slowly, over billions of years and by additions at the margins. This is quite different from how oceanic crust grows, at rates that are hundreds of times faster and by additions in the center. Then the Engels turned their attention to the oceans.

Menard tells about the transformation in his 1986 scientific autobiography *Ocean of Truth*: "At Scripps, Al became intrigued by the volcanic rocks that we had dredged from seamounts and the deep-sea floor ... Continental petrologists had not shown much interest in our dull grey rocks until Al and Celeste appeared. The next thing we knew, Al was feverish with excitement and talking constantly about 'low-K tholeiites' ... Al was in the process of proving that the seafloor consists of tholeiitic basalt, which is the most common rock on the surface of the earth." Celeste has a different perspective on the epiphany, recounted in her autobiography *Rocks in My Head* (Vantage Press 1987): "Al and I were sitting in the room where we stored all of our Precambrian rock specimens. We were looking at thin sections of metamorphic rocks through our polarizing microscope. We were facing a wall, but we could see the hall, too. Dr. Bill Riedel was walking down the hall with a wooden tray of rocks. Riedel stopped and visited for a while. "What do you have in the tray?" Riedel said, "These are igneous rocks, basalts, which have been dredged from the ocean floor by Scripps ships at various locations." ... Riedel came in and placed the tray on a table. Some rocks had thin sections lying beside the samples. "We would like to look at the thin sections," I said. "Okay, you can have them," he said. "To keep?" "Yes." After Riedel was gone, Al said, "Who would want to study basalts?" ... After we looked at the samples, we studied basalts from the ocean floor for over eight years."

Al and Celeste published two ground-breaking papers in *Science* during 1964, "Composition of Basalts from the Mid-Atlantic Ridge" and "Igneous Rocks of the East Pacific Rise." In 1965 they synthesized and summarized their results with a landmark paper in the *Bulletin of the Geological Society of America*: "Chemical Characteristics of Oceanic Basalts and the Upper Mantle." These papers gave birth to the field of marine igneous geochemistry, a subject that has grown tremendously over the past four decades. The Engels showed that, yes, the ocean floor was made of basalt, but of a kind found nowhere else on Earth. They called this basalt 'oceanic tholeiite,' a term that is more pleasing to the ear than the lifeless acronym 'MORB,' for 'mid-ocean ridge basalt' as such rocks are now called. Prior to these papers, many scientists thought that the oceanic crust was composed of basalt like the 'alkali' basalts erupted on volcanic islands. Those basalts are enriched in continent-forming elements, such as potassium, rubidium, uranium, and thorium. In contrast, oceanic tholeiites contained such low concentrations of these elements that at first Celeste's analyses were not believed. The Engels were happy to distribute their powders to any who requested them, thus precipitating a wide range of geochemical and isotopic studies. But her analyses were correct—oceanic crust was depleted in just those elements in which the continents were enriched. The Engels also showed that oceanic tholeiites were amazingly similar, whether they came from the slowly spreading Atlantic or the rapidly spreading Pacific. The crust of the oceans—70% of the earth's surface—was composed of the same material, and the Engels were the first to figure out what it was.

The Engels' breakthroughs about the composition of oceanic crust and mantle came at a critical time. Not only did they independently confirm that something quite remarkable was going on beneath the mid-ocean ridges, their work showed that understanding igneous rocks was essential to the rapidly growing field of plate tectonics. Those who wanted to understand how the planet operated would have to heed oceanic tholeiites and the constraints these provided on the composition of the upper mantle. For example, geophysicists measuring heat lost from Earth's interior were faced with a profound paradox. They knew that similar amounts of heat flowed through the seafloor and the continents, in spite of the fact that continental crust was thick and rich in heat-producing radioactive elements, whereas oceanic crust was thin and had almost none. The paradox could only be resolved if the mantle was hotter beneath the mid-ocean ridges than beneath the continents, indirectly providing independent support for the Hess-Dietz 'spreading seafloor hypothesis'. Later, geochemists used the composition of seafloor basalts to conclude that these were derived from depleted mantle, and that this depletion was caused long ago when melts were extracted to form the continental crust. Such massive melting of depleted mantle beneath the mid-ocean ridges required that something unusual was going on beneath them. We now know that this melting is caused by upwelling of mantle beneath the ridges, and that melting results as pressure is reduced.

After the 1965 *Geological Society of America Bulletin* paper, Al left marine geology to the marine geologists. The army of petrologists and geochemists devoted to the study of mid-ocean ridge basalts grew yearly. Once I asked why he didn't continue his studies of oceanic tholeiites, and he answered that as far as he was concerned there really wasn't much left to find out. Al thought that many subsequent studies of seafloor basalts were, in his words, "... a feeding frenzy over minutiae." The hundreds of scientists who have built on the Engels' pioneering studies would almost certainly disagree, but they would probably agree that the Engels skimmed much of the cream. Partly in recognition of these accomplishments, Al was elected to the National Academy of Sciences in 1970.

Engel's desk in New Ritter Hall, ca. 1979. Notice proximity of wastebasket to chair.

Al devoted himself to studying the formation and evolution of the continental crust for another two and a half decades. He studied ancient rocks of South Africa, Wyoming, and Egypt, taught classes on crustal evolution and field geology, supervised graduate student projects, and led Spring field trips to the California desert. But none of these efforts compared in impact with the contributions that he and Celeste made in our understanding of the oceanic crust, at a critical time when the seafloor spreading hypothesis was becoming plate tectonic theory.

Selected Bibliography (chronological order)

Engel, A. E. J., 1946. The quartz crystal deposits of western Arkansas. *Economic Geology*, v.41. pp.598-618.

Engel, A. E. J., and C. G. Engel, 1953. Grenville series in the northwest Adirondack Mountains, New York. Part II: Origin and metamorphism of the major paragneiss. *Geological Society of America Bulletin*, v.64. pp.1049-1097.

Engel, A. E. J., R. N. Clayton, and S. Epstein, 1958. Variation in isotopic composition of oxygen and carbon in Leadville Limestone (Mississippian, Colorado) and in its hydrothermal and metamorphic phases. *Journal of Geology*, v.66. pp.374-393.

Engel, A. E. J., and C. G. Engel, 1958. Progressive metamorphism and granitization of the major paragneiss, Northwest Adirondack Mountains, New York. Part I: Total rock. *Geological Society of America Bulletin*, v.69. pp.1369-1414.

Engel, A. E. J., and C. G. Engel, 1960. Progressive metamorphism and granitization of the major paragneiss, Northwest Adirondack Mountains, New York. Part II: Mineralogy. *Geological Society of America Bulletin*, v.71. pp.1-58.

Engel, A. E. J., and C. Engel, 1962. Progressive metamorphism of amphibolite, Northwest Adirondack Mountains, New York. In *Petrologic Studies: a Volume to Honor A. F. Buddington. Geological Society of America.* pp.37-82.

Engel, A. E. J., and C. G. Engel, 1962. Hornblendes formed during progressive metamorphism of amphibolites, Northwest Adirondack Mountains, New York. *Geological Society of America Bulletin*, v.73. pp.1499-1514.

Engel, A. E. J., 1963. Geologic evolution of North America. *Science,* v.140. pp.143-152.

Engel, A. E. J., and C. G. Engel, 1964. Composition of basalts from the Mid-Atlantic Ridge. *Science*, v.144. pp.1330-1333.

Engel, A. E. J., and C. G. Engel, 1964. Igneous rocks of the East Pacific Rise. *Science,* v.146. pp.477-485.

Engel, A. E. J., C. G. Engel, and R. G. Havens, 1964. Mineralogy of amphibolite interlayers in the gneiss complex, Northwest Adirondack Mountains, New York. *Journal of Geology,* v.72. pp.131-156.

Engel, A. E. J., C. G. Engel, and R. G. Havens, 1965. Chemical characteristics of oceanic basalts and the upper mantle. *Geological Society of America*, v.76. pp.719-734.

Engel, A. E. J., et al., 1968. Alga-like forms in Onverwacht Series, South Africa: oldest recognized lifelike forms on Earth. *Science*, v.161. pp.1005-1008.

Engel, A. E. J., 1969. Time and the earth. *American Scientist,* v.57. pp.458-463.

Engel, A. E. J., and C. G. Engel, 1970. Lunar rock compositions and some interpretations. *Science,* v.167. pp.527-528.

Engel, A. E. J., 1970. The Barberton Mountain Land: clues to the differentiation of the earth. In *Adventures in Earth History,* P. E. Cloud (ed.), W. H. Freeman and Co. pp.431-445.

Engel, A. E. J., and D. L. Kelm, 1972. Pre-Permian global tectonics: a tectonic test. *Geological Society of America*, v.83. pp.2325-2340.

Engel, A. E. J., S. P. Itson, C. G. Engel, D. M. Stickney, and E. J. Cray Jr., 1974. Crustal evolution and global tectonics: a petrogenetic view. *Geological Society of America Bulletin*, v.85. pp.843-858.

Engel, A. E. J., T. H. Dixon, and R. J. Stern, 1980. Late Precambrian evolution of Afro-Arabian crust from ocean arc to craton. *Geological Society of America Bulletin*, v.91. pp.699-706.

Engel, A. E. J. and P. A. Schultejann, 1984. A Late Mesozoic and Cenozoic tectonic history of south central California. *Tectonics*, v.3. pp.659-675.

Engel, C. G., 1987. *Rocks In My Head.* Vantage Press, New York. 203p.