2014

From Marsquakes to Terraforming: the Role of Planetary Geology in Science Fiction Literature

Katherine Shover 14

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Honor Scholar Thesis

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Author:
Katherine Shover

Committee Members:
Dr. James Mills
Dr. Arthur Evans
Dr. Istvan Csicsery-Ronay

DePauw University

Greencastle, Indiana

May, 2014

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Acknowledgments

This work would not have been possible without the encouragement and support of my committee. Many thanks to my advisor, Dr. Jim Mills, whose enthusiasm, guidance, and valuable advice I would never take for granite. I would also like to thank my convener, Dr. Art Evans, and my reader, Istvan Csicsery-Ronay, for their interesting and insightful comments.

I thank my father, Scott Shover, for inspiring my love of science fiction and faithfully reading my thesis drafts. I also thank my mother, Karen Shover, and my fiancé, Matthew Hellmann, for their continual support.

I would also like to thank the faculty and staff members of DePauw's Honor Scholar Program who guided me through this process, in particular Dr. Andrea Sununu for building and strengthening the foundations of my writing skills, and Amy Welch for her ever-cheerful email reminders.

Introduction

As ever more detailed images of other planetary bodies have emerged from various space expeditions, such as the crisp view of Saturn's rings taken by the Cassini–Huygens spacecraft in 2004, or the dusty landscapes of Mars from the Curiosity Rover in 2012, humans have acquired a clearer picture of our planetary neighborhood. Such images have captured the imaginations of those who seek to view and comprehend celestial bodies' geological features. One could argue that this greater collective understanding and rapidly-changing view of the natural world has been reflected in the evolution of the literary genre of science fiction (sf).

Older sf stories such as Cyrano de Bergerac's *States and Empires of the Moon* (1657) or Margaret Cavendish's *Blazing World* (1666) involved journeying to other worlds primarily for showcasing exotic fantasy or providing a platform for socio-political commentary. But around the mid to late nineteenth century, not long after the Enlightenment and the Industrial Revolution, more authors began treating such expeditions as realistic scientific endeavors, such as Jules Verne in his novels *From the Earth to the Moon* (1865) and *Around the Moon* (1870). Over time, other planetary bodies became more than just 'locations that aren't Earth' and instead became appreciated by some science fiction authors as places with their own unique characteristics and settings that can be incorporated into their sf stories. In sum, the fantastic views and greater knowledge of space in part led to the potential for other planets to be recognized as settings interesting enough to merit their own consideration as elements in a story.

A fundamental backbone of science, the scientific method, seems straightforward when taught at the basic level; one simply follows the steps of making observations, forming a hypothesis, testing that hypothesis, collecting data, analyzing the data, and coming to conclusions. However, the science of planetary geology is not quite so simple. One cannot

simply design an experiment to recreate a volcanic range on Venus or a billion years of wind-blown deposition on a Martian plain. While tools such as numerical models, small-scale laboratory experiments, and analytical comparisons of otherworldly features to terrestrial features can help unravel the mysteries of planetary geology, our knowledge of many aspects of planetary geology will inevitably remain uncertain or disputed, prone to conflicting hypotheses. The cost of obtaining data at such great distances is also an obstacle. But perhaps the additional challenges add to the allure, drawing both scientists and authors toward this field.

In practice, science offers models of the universe and how it works; somewhat similarly, hard science fiction offers models of imaginary futures, showing how human attitudes, actions and politics fit in with scientific models and speculating about how these models, in addition to people, will change in the future. One of the goals of this study is to assess the validity and realism of these various models based on accepted scientific knowledge. But first, I will look into how planetary geology interacts with these stories – as a setting, a reflection of characters' perceptions and outlooks, a driver of the plot, a source of conflict, and an end in itself.

In order to conduct this analysis, I have restricted the scope of this thesis to six modern sf novels: *Heart of the Comet* by David Brin and Gregory Benford (1986), the Mars Trilogy of *Red Mars* (1993), *Green Mars* (1994), and *Blue Mars* (1996) by Kim Stanley Robinson, *Ventus* by Karl Schroeder (2007), and *The Quiet War* by Paul McAuley (2009). These novels constitute a fairly narrow chronological selection, but together they constitute a good representative sampling of modern sf works on planetary geology. All are "hard" science fiction novels, with ample scientific content and a focus on scientific accuracy. Further, through these novels, many different aspects of planetary geology are portrayed.

A Short Overview of the Core Texts

With the vast scopes and expansive ideas covered in these novels, it is not surprising that all six core texts are narrated from multiple perspectives. For the most part, the novels use the third person perspective for a set cast of characters, although some also employ an omniscient narrator, such as the italicized passages in the Mars Trilogy used to convey different Martian perspectives or explain ideas such as the geologic development of Mars. The many character perspectives give the readers a variety of views of the science, some more informed than others.

Heart of the Comet follows three main characters – Carl, Virginia, and Saul – plus the rest of the scientists sent to study Halley's Comet. The crew faces a series of hurdles, from surviving quakes to handling the newly-discovered cometary life to countering prejudices left over from their time on Earth. With two more main characters than *Heart of the Comet*, *The Quiet War* features the perspectives of scientist Sri Hong-Owen, young clone Dave #8, microbial ecologist Macy Minnot, self-serving diplomat Loc Ifrahim, and starship pilot Cash Baker. The events of the novel revolve around the looming war between the free-wheeling Outers, who inhabit the moons around the gas planets of the solar system, and the more conservative inhabitants of Earth. As in *Heart of the Comet*, the characters must face not only physical dangers, but also their own prejudices and moral struggles.

Ventus contains a perspective from almost every major character, plus a few one-shot minor characters like a grave digger or a young man on the run from the Winds. The nature of the artificial intelligences (AIs) that terraformed the planet Ventus constitutes the central mystery of the novel. Like *Ventus*, the Mars Trilogy has almost too many character perspectives to list, thanks to the immensity of the scale and time span of the three novels. Overall, the trilogy follows the story of Mars' terraforming. *Red Mars* covers Mars' colonization, terraforming in its

beginning stages, and the Martian Revolution; *Green Mars* focuses more closely upon the terraforming process but also covers the second revolution; and *Blue Mars* depicts the longer-term effects of terraforming Mars and expands its view to the rest of the Solar System.

What is Planetary Geology?

Before delving into the variety of roles that planetary geology plays in science fiction literature, it is important to determine exactly what the term 'planetary geology' means. One textbook defines it as "the study of surface and interior processes on solid objects in the solar system: planets, satellites, asteroids, comets, and rings," but also mentions the elements of "exploration and discovery" and points out its "cross-disciplinary" nature (*Remote Sensing*). Like terrestrial studies of geology, planetary geology draws from other fields of science, such as chemistry, physics, and even biology. From using chemistry to measure the water content of Moon rocks to utilizing physics to investigate the existence of ancient earthquake-triggered floods on Mars, planetary geology incorporates knowledge and techniques from other fields to gain a clearer understanding of celestial bodies.

A degree of controversy is associated with planetary geology, with some questioning the merit of such studies, due to the considerable distance and costs associated with acquiring data. Recent cuts by the Office of Management and Budget to funding for NASA's Planetary Science Program are one example of the declining weight that some allot to space exploration (Nye). While not as useful or interwoven within a typical person's life compared to fields such as medical biology or agricultural genetics, planetary geoscience nevertheless has its proponents, who address these concerns with an array of responses. The popular science educator Bill Nye, also the CEO of the Planetary Society, highlighted not only the "astonishing discoveries from other worlds" and innovations that the planetary science division has brought, but also the "new businesses and economic growth" that result (Nye). Many sf novels, including the core novels of this thesis, also address questions relating to the merit of space exploration. Some counter planetary geology's detractors by espousing the acquisition of knowledge and the process of

exploration for their own sakes, while others point to the side benefits for Earth that come from the development of space-worthy technology and pursuits. NASA itself now produces annual reports on its numerous benefits to the public, organized into quantifiable categories of "jobs created; revenue generated; productivity and efficiency improvements; lives saved/not lost; and lives improved" (Comstock, Lockney, & Glass). Safety and prevention of threats, such as meteorites smashing into the Earth, are touted by pessimists supporting the study of planetary geology, while optimists speak of the possibilities of colonizing other planets and moons, and even making these places more hospitable through terraforming. Taken all together, reasons for studying planetary geology abound, and studies in this field have helped form the knowledge base from which hard science fiction authors draw in order to construct realistic stories set in otherworldly locations.

Planetary Geology in the Texts

Setting the Scene for Inspiration, Education, and Character Development

Of the many roles that planetary geology plays in science fiction, its contribution to the settings of the stories is most apparent. In all six sf works examined in this study, it is easy to spot the many vivid examples of planetary geology developed throughout the novels. One could simply dismiss such examples as mere fluff; however, a closer look reveals the multifaceted nature of these descriptions, which can serve to inspire and educate the readers while making connections between different places and contributing to character development. For example, in the third book of his Mars Trilogy, *Blue Mars*, Robinson provides one character's powerful reaction to a sea-side view:

> Then as they continued, the horizon below them to the east seemed to double: Chryse Gulf, gleaming blue and flat, still far below. As they continued to follow the caribou downslope, the sea covered more and more of their view of the globe; the Great Escarpment pitched so steeply here that even Mars's tight curvature did not bend fast enough to hide the long view, and they could see out over Chryse Gulf for many kilometers. The sea, the blue sea! (470)

Given that Mars was a dusty, barren, red planet two centuries ago, its rapid transformation into a place where the blue sea can stretch past a person's line of sight is simply astonishing. This description manages to convey the enormity of the changes that humans have wrought upon Mars through one individual's perspective. This passage also demonstrates *Blue Mars'* status as a hard sf novel with the tidbit about Mars' tight curvature, which includes a quick fact about Mars to show how its smaller radius affects the view of the landscape from the surface. In doing so, this passage reveals another purpose for descriptions of planetary geology: education.

By integrating explanations of scientific processes such as aluminum isotope decay (Brin and Benford 93) or the mechanics of landslides near the edges of glaciers (Robinson, *Green Mars* 114) into descriptions of planetary geology, science fiction authors can educate and inform people about topics they find interesting. For instance, David Brin, co-author of *Heart of the Comet*, wrote his Ph.D. thesis on a related topic: "The Evolution of Cometary Nuclei as Influenced by a Dust Component." It seems reasonable to assume that he would have wanted to share his enthusiasm for comets in his book. Describing the change in appearance of the comet along its path away from the sun, Brin and Bedford write, "beyond the orbit of Mars, the sun's violent heating no longer boiled off the huge jets of water molecules, dust, and carbon dioxide that made Halley so spectacular during its short summer" (7). This description not only provides a spectacular image of a burning comet, but also subtly informs the reader of the main chemical components of a comet's tail. The authors also cleverly incorporate educational content into the characters' conversations:

> This was just a flying iceberg for billions of years, out beyond Neptune. But back when the solar nebula condensed there was a lot of aluminum 26 in Halley; Chem Section reported finding the decay products, remember?
>
> —Oh yeah, residue from the same supernova that triggered formation of the solar system. (Brin and Benford 93)

By combining dialog with the intricate details about the comet's chemical composition and the origin of particular elements present, Brin and Bedford refrain from delivering a lecture about the comet to the reader and instead impart the information through a more informal medium, showing rather than telling the readers about these chemical characteristics.

Also with an educational focus, science fiction authors sometimes use their descriptions of planetary geology to make connections between Earth's geology and the geology of other planets and moons, a practice that planetary geologists often use for analysis. For example, Robinson begins one chapter of *Red Mars* with a detailed, factual description of the red planet: "Mars is small but heavy, with a nickel-iron core. It is small enough that the interior has cooled faster than Earth's; the core no longer spins inside the crust at a different speed, and so Mars has practically no magnetic field" (94). These details help build the background for the significant problem that the colonists face in preventing radiation exposure on a planet that, unlike Earth, has little shielding from radiation due to its lack of a magnetic field. In another example, Paul J. McAuley's *The Quiet War* notes the Earth-born character Sri's surprise at the familiarity of the landscape of Saturn's largest moon, Titan: "They were flying north above what was clearly a volcanic range, domes and complex calderas strung across broad, dark outflow slopes dissected by brighter channels and fissures and collapse depressions" (383). In addition to painting a vivid picture of the characters' current location, this descriptive passage also draws connections between terrestrial geology and the "clearly" similar features of Titan, showing how similar geologic processes and principles apply across the solar system.

In a more poetic vein, sf authors also simply seek to inspire their readers with the beauty and wonders associated with exploring other planets. McAuley's young characters in *The Quiet War* literally fall to their knees, "arms wrapped around their big round helmets," when confronted with their first view of the Moon's surface, described as "a desolate plain stretching away toward a range of hills, softly rounded as pillows, that curved from horizon to horizon" (133). *Heart of the Comet* features a quieter, simpler form of contemplation: "Virginia found it beautiful. The dark regolith was laid bare, here and there, exposing a slumbering icy substrate.

Although a thin coma of shimmering ions still hung overhead tenaciously, the vault already showed more stars than the dark, tropical nights back home" (Brin and Benford 83). The readers are able to put themselves in Virginia's place, envisioning the glittering light from above. Furthermore, the personification of the icy substrate, coupled with the juxtaposition of the view of the stars on the comet versus the view from Earth, brings the otherworldly nature of the comet to life. Not only do these descriptions help build the setting, but they also convey a sense of wonder through the characters' reactions and perceptions.

Even without character involvement, descriptions of planetary geology from a narrative perspective can be used to inspire the audience. This passage from *Ventus* serves as one such example: "Diadem, the only moon of Ventus, was up and glittering like a tear. The rest of the sky was clear and splashed with stars, rank on rank, gauze on gauze of finest points of white. The river of the galaxy ran across the zenith" (Schroeder 65). Here Schroeder uses lyrical, almost poetic language, employing similes and metaphors to paint a view of the sky from another world. Robinson also utilizes rich, expressive descriptions and poetic language to share his picture of another world.

> The colored sands in their patterns, the fluted and scalloped canyon walls, the volcanoes rising right through the sky, the rubbled rock of the chaotic terrain, the infinity of craters, ringed emblems of the planet's beginning. . . . Beautiful, or harsher than that: spare, austere, stripped down, silent, stoic, rocky, changeless. Sublime. The visible language of nature's mineral existence." (*Red Mars* 96)

Robinson's long passages describing the Martian terrain flesh out a complex world filled with a diverse array of features. The flowing line of adjectives in the passage above reinforces the unique nature of the planet's surface with a mosaic of listed qualities. Such detailed depictions

convey the beautiful, inspiring natures of other celestial bodies, in addition to contributing to the world-building of the story.

Along with their world-building, inspirational, and educational purposes, descriptions of planetary geology can also contribute to character development. In the previous passage, Sri was flying above Titan in order to meet with the renowned researcher Avernus, whom she had been persistently attempting to contact for months. Yet when her goal of meeting with Avernus was almost within her grasp, Sri still took the time to examine the landscape, demonstrating her inquisitive, scientific nature. Another way that planetary geology can be utilized for character development is through the use of basic literary devices. In Karl Schroeder's *Ventus*, a simile conveys a character's distress: "Tamsin's shoulders were slumped like the dunes. The farther they went into the desert, the more despondent she became" (436). Connecting the dunes to the drooping geometry of a depressed young woman's shoulders serves to convey her mood in an engaging way while highlighting a geological feature of the fictional terraformed planet Ventus. Similarly, to show that geologist Ann Clayborne from the Mars Trilogy was crying, Robinson wrote, "It hurt – her body, spasming in a seismic trembling" (*Blue Mars* 259). While not specifically related to an instance of planetary geology, the reference to seismicity is a reinforcement of Ann's identity, which she strongly associates with her career and passion: the planetary geology of Mars.

The Impact of Planetary Geology on Individuals

When the characters in these sf texts travel to other planets, moons, and comets, some find beauty and solace in the unfamiliar new settings of other planetary bodies, whereas others suffer from homesickness and despair due to their desolate surroundings. The former category of

characters appears in Brin and Bedford's *Heart of the Comet* when two friends find a crystal cavern within the ice. Carl, a member of the setup crew on the comet Halley, gasps at the sight, in which "Crystalline facets sprouted everywhere. Points gleamed ruby red, emerald, burnt orange. Wherever he turned his helmet lamps, refracted light came back in brilliant splinters" (94). His friend Lani, who first discovered the cavern, uses pictures of it to decorate her personal living quarters, in contrast to the majority of spacers who display scenes from Earth. Clearly, the striking alien beauty of the crystal cavern resonated with these individuals. And in Robinson's *Red Mars*, the beauty of the red planet so affected geologist Ann Clayborne that she campaigned relentlessly against terraforming the planet and spearheaded the creation of a political party, the Reds, a group that generally reflected her values and aims with respect to terraforming. In terms of the hard scientific sense of wonder, these characters demonstrate the "dynamic sublime," a term for the "response to the sheer physical presence of powerful phenomena, to the superhuman force manifest in magnificent geological formations, waterfalls, storms; that is, those aspects of nature that cause the ego to feel small in the world" (Csicsery-Ronay 149). Whether a massive array of crystals or the entirety of a desert planet serve as inspiration, the geological features present often inspire and shape the lives of various characters.

On the other hand, not every character views the geology of non-terrestrial bodies with such delight. *Red Mars*' homesick psychologist, Michel Duval, climbs up four hundred stairs to observe Underhill Plain on Mars, but while "each step gave him a wider view … but it was still the same sere and barren rockpile, no matter how large it got" (Robinson 222). Not much later, Michel asserts, "the bleak plain surrounding the base was a vision out of some post-holocaust desolation, a nightmare world" (Robinson, *Red Mars* 215). Depressed, Michel draws no comfort from his surroundings, perceiving only a somber, dreary world surrounding him on Mars. The

other sf texts of this thesis also contain examples of negative perceptions of the planetary geology, but one thing to note is that these dark thoughts often share a common literary purpose: to reflect the emotional state of the character.

When people feel hopeless, face great danger, or perhaps are just having a bad day, their perceptions of the world around them are often tainted by their gloomy mood. Authors can convey such feelings in part by portraying descriptions of the surrounding geology as seen through the characters' eyes, colored by their emotions. For example, in *The Quiet War*, bio-engineer Macy Minnot takes note of her surroundings while escaping from the city in which she was held captive: "The capsule was transparent and there was nothing outside its thin wall but killing cold and hard, radiation-drenched vacuum. High above, the sun's tiny disc burned close to Jupiter's skinny crescent" (McAuley 185). Considering that this is the same character whom the prison wardens repeatedly reprimanded for staring around at the scenery of Jupiter's moon Ganymede instead of completing her required physical labor (McAuley 168), such pessimism seems uncharacteristic and is likely a product of her stressed state of mind. This interpretation is further supported by her assertion, during another stressful event (being kidnapped), where "everything looked bare and bleak and nakedly hostile" through her pressure suit (McAuley 279). In a similar manner, the Mars Trilogy's Nadia Cherneshevsky connects the battering of the winds from a potentially-deadly dust storm to her negative feelings: "Once out of the sling she found herself leaning into the wind; thin as it was it still struck like blows, and her old feeling of hollowness was extreme" (Robinson, *Red Mars* 197). As these examples have shown, characters' responses to their surroundings often depend upon their circumstances.

However, awe and negativity are not the only emotions reflected in the characters' perceptions of the surrounding planetary geology; examples of ambiguous and positive feelings

also abound. Virginia seems torn as she observes her surroundings on Halley in *Heart of the Comet*: "As she stepped onto the surface she felt again the chilly majesty of the ice, the void, the swallowing darkness they all swam in. Earth is the sultry Hawaii in a solar system of perpetual Siberias, she thought. Will we ever feel true warmth again?" (Brin and Benford 383) While noting the "chilly majesty" of her cold surroundings, she also experiences feelings of homesickness and longing for her warm, hospitable home planet. Lacking the ambiguity of Virginia's feelings, Armiger from Schroeder's *Ventus* expresses evident satisfaction with the sight of Ventus' moon, Diadem:

> The moon received its name from the scattering of brilliant white craters on its surface, which made it a dim oval studded with diamond-bright pinpricks of light. On other nights Armiger had praised or cursed those gleaming points, depending on whether night-visibility was to his army's advantage or not. Tonight, possibly for the first time, he was able to admire the sight for its own sake. (156)

In addition to demonstrating Armiger's contentment at the sight of Ventus' foremost geological feature, this passage also reflects the process of Armiger becoming more human: a major development point in which this man so altered by artificial intelligence (AI) reverts back to his original nature, becoming more prone to emotional moments of reflection and less relentlessly rational and machine-like. Planetary geology can change a person.

The Impacts of Humanity on the Planetary Geology

The previous section detailed the many ways in which geological features of the many planetary bodies featured in these sf texts affected different individuals. However, this cause-and-effect relationship is not a one-way street. In addition to the geology affecting the people,

the people most certainly affect the geology in return. Through actions both large and small, the human interlopers on these planets, moons, and comets leave traces of their presence and even change the geologic nature of the celestial bodies they inhabit.

Unlike today's world, in *The Quiet War*'s postulated future, footprints on the Moon are no longer rare or particularly significant; these little imprints of human activity litter the surface. The young soldier Dave #8, a clone living on a secret military base on the Moon, notes during a surface exercise that "his boots and the boots of his brother printed sharp impressions in the dusty surface; when he paused and looked back at the way they had come, he saw an intertwined double track of prints that shone glassily in the relentless glare" (McAuley 134). In addition to the markings left behind by people walking, another imprint of the human presence – roads – cut up the landscapes. On one of Saturn's moons, Macy Minnot drives upon a road which "cut through a series of ridges softened by a mantling of dust created by several billion years of micrometeorite impacts" (McAuley 237). This plain took billions of years of accumulation to form, yet humans spent only weeks building the road that cuts across it. One character from Robinson's Mars Trilogy, Ann Clayborne, is sharply aware of and devastated by these irreversible alterations, so much so that she proclaims, "This road we made, it hurts me to see it!" (*Red Mars* 157). Human alterations to other planetary bodies not only have a physical effect on the landscapes, but can also evoke feelings of anger and disgust in humans.

As on Earth, humans in outer space generate waste materials that must go somewhere. When digging down into Halley's Comet for shelter, the scientists from *Heart of the Comet* create "high, peaked pyramids of dark tailings from shaft evacuations, crudely separated into heaps of primordial nickel-iron, platinum- and iridium-rich ores, and carbonaceous gunk . . . much like the Alberta tar sands" (Brin and Benford 86). The reference to the Alberta tar sands

serves as a reminder that problems such as pollution and scarring of the landscape do not disappear outside of Earth. The dump and "great salt pyramids" near Underhill, the first Martian settlement in *Red Mars*, (Robinson 211) further demonstrate this concept. In addition to tailings from industrial processes, items and debris originating from broken machines and similar garbage can also cover a landscape. "Trash-strewn snowfields" (Brin and Benford 284) in which, according to Carl, "It was hard to tell what was an intentional experiment and what was yesterday's garbage" (Brin and Benford 30), litter the ice around the main settlement. On Ventus, trash even accumulates for frivolous reasons; for example, offerings to the indifferent Winds, AIs responsible for Ventus' terraforming process, fill one ruined temple (Schroeder 527). Clearly, these authors imagine that humanity's propensity for generating waste does not remain confined to Earth.

In addition to these comparatively small alterations of roads and dumps, the process of terraforming constitutes a massive change to a planetary body's geology. In *Red Mars*, the influx of water on the surface from the earlier stages of terraforming drastically changes the landscape; daily freezing and thawing accelerates mass wasting, resulting in thousands of boulders tumbling down each day (Robinson 541). After about a hundred years of terraforming efforts, according to its despairing opponent, Ann Clayborne:

> Red Mars was gone, and gone for good. Soletta or not, ice age or not, the biosphere would grow and spread until it covered everything, with an ocean in the north, and lakes in the south, and streams, forests, prairies, cities and roads, oh she saw it all; white clouds raining mud on the ancient highlands while the uncaring masses built their cities as fast as they could, the long run-out of civilization burying her world. (Robinson, *Blue Mars* 44)

While some calderas and canyons were tented to preserve the conditions present before humans began tampering with the planet's surface and atmosphere, the overall nature of Mars had been irrevocably changed in order to facilitate human habitation on the planet. Some, like Ann Clayborne and the Reds, fought and mourned the process, while enthusiasts such as scientist Sax Russell facilitated the mechanisms of terraforming, such as drilling water to the surface or mining nitrates for release of nitrogen into the atmosphere (Robinson, *Green Mars* 156).

Some of the scientists in *Heart of the Comet* had aspirations for Mars similar to Russell's, but centered around the use of comets in the terraforming process. By steering some comets into the inner solar system for harvesting and colliding other cometary nuclei into Mars, these proponents of terraforming hoped to "build up an atmosphere, perhaps even get the volcanoes spouting again" (Brin and Benford 68). A political movement, symbolized by a flower with a circle around it, puts its hope in the terraforming process to provide a safe haven for genetically-altered humans who face discrimination and suspicion on Earth and therefore desire to find a new home on Mars. Ventus' terraforming process also involved comets and political intrigue. Hamburg, the Earthly home of the Ventus terraforming project, also housed the thalience movement, described by its founders as a discipline "not concerned with scientific truth, but rather with establishing personal and cultural relationships between human beings and the physical world that make the true natures of both comprehensible to us" (Schroeder 597). A controversial concept viewed as heretical and anti-scientific by most of the people on Earth, the principles of thalience were nonetheless embedded into the AIs used to terraform Ventus. In the terraforming process itself, the main goals were altering the atmosphere and constructing a soil base. Nearby asteroids provided a home for the machines needed for terraforming to multiply, gigantic solar mirrors increased insolation, and harvested comets contributed oxygen to the

planet's atmosphere (Schroeder 497). Unlike the schemes for Mars in *Heart of the Comet*, the plans for terraforming *Ventus* came to fruition and resulted in a planet suitable for human habitation, but requiring continual maintenance for the changes to stick.

The Ethics of Altering Other Worlds

As the previous section described, human inhabitation of other planetary bodies almost inevitably results in changes to the landscape and alteration of that body to some degree. Terraforming in particular produces massive changes to the planetary environment. Existing international policies and agreements about conduct in outer space are vague on the topic of terraforming; however, the 1967 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, with 102 Parties and 26 Signatories, does address the environment in Article IX, which states that "Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination" (UNOOSA). Since existing laws on terraforming are so scarce, not to mention that most sf stories are set in the future, sf authors generally have free rein to explore various viewpoints and debate the merits of terraforming on their own terms.

Some argue for limitations to terraforming due to the impediments the process poses to acquisition of knowledge. The Mars Trilogy's Ann Clayborne and her allies from The Journal support this line of thought, advocating "the preservation of the primal landscape so that studies could be carried on without having to deal with gross contaminations" (Robinson, *Blue Mars* 26-27). This faction does not absolutely oppose terraforming, but they first wish to gather data and learn more before forever altering the evidence of Mars' geological history. As Ann simply

states, "you can't just wipe out a three-billion-year-old planetary surface" (Robinson, *Red Mars* 40). Quiverian, a scientist from *Heart of the Comet*, shares similar sentiments. Arguing against a proponent of terraforming, Quiverian exclaimed, "The original idea was to study comets, the most pristine of all God's handiworks. But now knowledge for its own sake doesn't seem to matter anymore. Now you not only want to harvest this comet, but recklessly alter entire worlds before we even understand them!" (Brin and Benford 50). Again, a scientist seeking to acquire knowledge implores his colleagues to take their time before seeking to transform an entire world. However, Quiverian's argument also evokes a more aesthetic line of argument, referencing the immaculate, unspoiled condition of the comet before the humans' arrival. Some extend the reasoning behind nature preserves on Earth to the preservation of natural habitats on celestial bodies.

Preserving the land for the land's sake is another argument against terraforming. One character perceives Ann Clayborne as a believer "in some kind of intrinsic worth for the mineral reality of Mars; it was a version of what people called the land ethic, but without the land's biota. The rock ethic, one might say. Ecology without life. An intrinsic worth indeed!" (Robinson, *Green Mars* 145). Ann's views align with the notion of environmental preservation, intending no use of the land, as opposed to conservation, a movement which seeks to use the land effectively. Opponents of preservation often find such attachment to lifeless settings ridiculous, decrying preservationist groups such as the Reds as fanatical members of a "rock-worshipping sect," but as the conflicts between the Reds and the Greens in *Blue Mars* show, this position clearly resonates with many people (Robinson 27). In fact, the dominant position of Earthlings in *Heart of the Comet* is an inclination toward preserving the natural settings present on other planetary bodies. Most spacers aboard Halley dismiss such talk as "nothing more than Luddism" due to the

"vast resources" available in outer space. In contrast to the limited and depleted supplies on Earth, space was perceived as a rich frontier with resources ripe for the taking. However, not everyone has such a utilitarian view of space. Saul Lintz notes the absence of the comet's natural beauty, with "dark glittering of carbonaceous hydrate, veined with shiny seams of frozen gas," in the dining hall, where "pink fiberthread and bright yellow spray-on sealant hid the primordial stuff of Halley Core" (Brin and Benford 72). In Saul's eyes, the artificiality of the environment "resembled some vast cathedral of kitsch" (Brin and Benford 72); the human-wrought changes to the comet appear gaudy and cheap compared to the majestic nature of the comet's ice. While some understandably take a more practical view of using the resources of planetary bodies, others cannot forget the more fanciful, aesthetic considerations.

Proponents of terraforming also make both mystic and scientific arguments to support their positions. Many of the Greens, the political counterpart to the Reds in the Mars Trilogy, follow the biologist Hiroko's lead in the mystical worship of viriditas, "that greening fructiparous power within, which knows that the wild world itself is holy" (Robinson, *Red Mars* 229). Originating from the Christian mystic Hildegard from the middle ages, the term "viriditas" itself implies a more spiritual point of view (Robinson, *Red Mars* 211). On the other hand, the majority of the early colonists on Mars supported terraforming due to the high level of radiation present, which forced them to live in tight underground quarters. As a major driver of the terraforming effort, Sax Russell argued: "If we don't do something to lessen it, we may not be able to stay here. We need a thicker atmosphere to cut down on radiation" (Robinson, *Red Mars* 171). Additionally, a thicker atmosphere would open up possibilities for emigration to Mars, easing population pressures on humanity's home planet. Malenkov, a scientist from *Heart of the Comet*, also enthusiastically envisions the many possibilities that altering and exploiting celestial

bodies can bring: "We might find more useful chemicals, maybe, like those Joao and Captain Cruz found on Encke. Why, there may even be some merit in that wild idea to use comets to terraform Venus or Mars! Eventually they might be made suitable for colonization" (Brin and Benford 49). Whether they're religiously motivated or scientific problem-solvers, supporters of terraforming tend to prioritize Earthly life and future possibilities over existing planetary conditions.

The free-wheeling Outers of the *The Quiet War* brook no debates regarding the ethics of altering other planets; rather, such processes seem to be a given, and the strong environmental movement on Earth remains grounded on the planet. In this universe, the brilliant scientist Avernus seeds Titan, one of Saturn's moons, with organisms that resemble "trees on the slopes; sponges in the pools … lichen analogues on the rocks," and as Sri scathingly observes, "It's very like Earth" (McAuley 387). Avernus defends her work, arguing that she prefers to use her "standard of beauty from Earth" in her garden creations, while Sri contends that "People like us need no common standard … we should be free to create anything we want" (McAuley 387). While neither woman views the terraforming itself as harmful, the content of the creations is a point of dispute. Sri's position is somewhat ironic, given that she's so keen on restoring her natural habitat dome in the Arctic back on Earth.

A dichotomy seems to exist between the values attributed to Earth's environment versus the environments of celestial bodies. While the dominant religion on Earth celebrates the planet's sacredness and the Earth-goddess Gaia, and environmental restoration remains a high priority, other celestial bodies are viewed as ripe for the taking and open to alteration. Vacuum organisms, light-absorbing black microscopic bio-machines used for mining, inhabit large swathes of land on Jupiter's moon Callisto, creating stark patterns on the surface. According to

one visitor to a vacuum-organism farm, "Travelling in the rolligon along the raised road that cut through the fields of tan dust was like passing over a vast page of some ancient manuscript printed in the hieroglyphic script of a forgotten language" (McAuley 97). This surficial alteration demonstrates the supremacy of resource acquisition over the aesthetic value of preserving the landscape.

Ventus' unique take on terraforming almost belongs in a category of its own among these sf novels. When the methods behind Ventus' terraforming process are revealed, the terraforming debate seems like a foregone conclusion. According to the Winds, AIs responsible for terraforming Ventus, upon their arrival, "the local life was not robust enough to survive what we were going to do, but that was considered a good thing" (Schroeder 497). The human desire to colonize a new planet clearly trumps the preservation of alien life forms and aspects of their worlds, since the agents of terraforming apparently have nothing in their programming to address these issues.

However, hidden within the programming of Ventus' terraforming system was a directive for "giving a voice to Nature itself, using artificial intelligences" (Schroeder 598). According to Marjorie Cadille, founder of the thalience movement, "the ultimate motivation for science is mastery of Nature, when investigation proceeds as an interrogation" (Schroeder 598). Thus, in order to further their aim of humanity communicating with Nature instead of dominating it, the backers of the Ventus terraforming project devise a system in which the AIs develop new ways of thinking, with the embedded tech advocating for the physical objects they occupy. Schroeder demonstrates this process vividly:

> Billions of pipsqueek voices contended in the sand: Silica grain! Carbon grain! Quartz pebble! they shouted. They buzzed and changed frequencies, inventing new

> communications modes and trying them on their neighbors. Each pinprick of sand was crusted and invaded by tendrils of nanotechnological filament that constantly probed and investigated it. The nanotech tried to make sense of where it was and what it clung to. It traded data with its neighbors to that end. (625-26)

Down to the smallest grains, the AIs attempt to understand the planetary geology, ecology, and other aspects of this world. The thalience-based programming of the terraforming agents on Ventus reflects a concern for the insights that nature can provide, yet the destructive nature of the terraforming process itself appears to contradict this concern. One way to resolve this apparent contradiction is through a utilitarian lens, in which giving a voice to nature provides humans with more knowledge and answers to their questions about the universe. The intrinsic and aesthetic values of Ventus' original nature were not viewed as important by the originators; the goal was to uncover truths for human benefit by overcoming the dominance of the human perspective alone.

In these sf texts, the authors bring up a variety of issues surrounding human presence on other celestial bodies. Some novels, briefly in *Heart of the Comet* and at length in Robinson's Mars Trilogy, address the ethics of initiating the terraforming process itself, whereas novels like *The Quiet War* and *Ventus* seem to view terraforming as an inevitable process. However, novels in the latter category do join the former in exploring debates regarding the purpose and contents of terraforming efforts, and the degree to which terraforming can inform human knowledge.

Obtaining and Exploiting Celestial Resources

With or without terraforming in mind, most space explorers share a common concern: obtaining resources. Essential materials such as useful metals and water, for its own use or for

growing food, must be obtained in order to facilitate long-term human habitations on celestial bodies. At the turn of the millennium, NASA reported that "it costs $10,000 to put a pound of payload in Earth orbit" (Dunbar). With such high costs, shipping all of the needed supplies from Earth is prohibitively expensive and unsustainable; thus, those who leave the Earth's bountiful habitat must find other ways to acquire the things they need.

Water

Integral to almost all forms of life thus-far discovered, and definitely for humans, water tops the list of essential resources for any space explorer. In *Ventus*, due to the planet's unique form of terraforming that is driven by AIs, the acquisition of potable water did not pose a problem for the characters. Descriptions of running water, thunderstorms, and rivers throughout the novel demonstrate the abundance of this vital resource. However, though the planet contains an adequate supply of water, the distribution of this resource still requires some maintenance from the artificially intelligent drivers of the continuing terraforming efforts. One observer of these processes conveyed his view of such events to a main character, Jordan: "There they found the desals hard at work, flooding the sands to strain salt from ocean water that poured in from the Titans' Gates--those are the Wind-built dams at the seaside. They pumped the newly freshened water deep into the earth. We know now that it comes up again through springs all across the continent" (Schroeder 300). Without this intervention, the humans on the surface may have struggled to obtain water in certain areas.

As in *Ventus*, the explorers from *Heart of the Comet* did not encounter major problems obtaining water, mostly due to the fact that Halley's Comet is composed largely of ice and dust, with water vapor making up around eighty percent of emissions from the nucleus (McPhate et

al.). For scientists capable of intercepting a comet to set up a research base on its surface, extracting water from the readily-available ice seems a relatively simple task. However, for space industries in general within this novel's universe, the need to acquire volatiles to serve as propellants and support biospheres prompted investments in ventures such as a small, unsuccessful ice mine on Ganymede, one of Jupiter's moons (Brin and Benford 40). In *The Quiet War*, another of Jupiter's moons, Callisto, is exploited for its water resources as well; as a world covered in water ice, this moon has no shortage of water, but its freezing surface temperatures sustain ice "hard as granite" that requires an elaborate process of mining, melting, and filtering of harmful compounds to become exploitable and safe for human consumption (McAuley 45).

While some of these settlements on celestial bodies have few problems with water acquisition, others do not fare so well. Mass emigration from an overcrowded Earth to the sparsely-populated Moon in *The Quiet War* is prevented due to the lack of water, meaning that only a few groups of people inhabit Earth's closest planetary body. For the original one hundred colonists in *Red Mars*, water shortages also presented a problem. After their arrival in Underhill, the colonists resorted to extracting water from the atmosphere, but in order to expand their operations and improve their living conditions, the colonists required a much larger amount of water. Their demand for water eventually grew so strong that the lead geologist of the expedition, Ann Clayborne, planned an expedition to the polar cap in order to establish a robot distillery to mine and transport water back to their base (Robinson, *Red Mars* 133). However, as the terraforming process proceeded, the availability of water grew, with the commonly implemented ice-drilling rigs in *Green Mars* paving the way for easy water access. By the time of *Blue Mars*, as its name suggests, liquid water freely runs and pools on the surface, thanks to

the massive terraforming efforts that warmed the atmosphere and brought such a high volume of water up from the subsurface. Due to the increased availability of water, the changes wrought upon Mars cascade across planet, affecting landscapes, ecologies, the economy, and society itself.

Food

While food is not a resource that can simply be mined and consumed on other celestial bodies, aspects of planetary geology play a hand in the cultivation of this essential substance. For example, in *Ventus* humans use their knowledge of the desals, AIs that implement pieces of the terraforming process, to arrange their planting season: "The desals flood the desert every spring," he said. "The Iapysians seed it in anticipation of the event, and harvest what comes out. The desals are using the desert as a salt trap, and don't really mind if the humans introduce life there. It probably saves them some trouble, in fact. A good arrangement, so Iapysia has thrived for centuries" (Schroeder 251). In *Heart of the Comet*, the task of sustaining a food system for those inhabiting a comet rattling around the Solar System exceeds the difficulty of growing crops on the surface of a successfully terraformed planet like Ventus. Multiple approaches serve as fail-safes in the event of one food source's failure: a hydroponics pod on the spaceship, farms below the surface, and greenhouses lit by mirrors on the surface all contribute to the scientific colony's food supply (Brin and Benford 259).

As in *Ventus*, the Mars Trilogy's food system is heavily influenced by the terraforming process, but in terms of technological sophistication, the Mars Trilogy more closely matches *Heart of the Comet*, except with far more details describing the mechanics of obtaining food. At first, in *Red Mars*, Mars' inhospitable atmosphere dictated that plants be grown in greenhouses,

in which scientists tweaked the atmosphere for maximum productivity: "the farm air was tailored to the plants, heavy on CO_2 and short on oxygen" (Robinson 14). By *Blue Mars*, terraforming progressed to the point that "vast green pastures … dotted by big wooden farmhouses" (Robinson 191) serve as fodder for cattle. As scientists sought to tackle the problems of mass producing soil, one engineer – Nadia Chernyshevski – used her knowledge of Martian clays to speed along the process. Since she knew that Martian smectites, a type of clay, were aluminosilicates and thus open to water and expansion, she came up with the idea to introduce veins into a soil horizon by adding water and letting it dry, after which they would "pour in whatever important bacteria and other constituents they could grow," which facilitated greater interaction of different biota within the soil (Robinson, *Blue Mars* 334). In this example and many others, Robinson intricately weaves scientific knowledge and speculation from planetary geology and other related scientific fields in order to address potential problems with necessities such as the food supply, building both knowledge and suspense.

Like Robinson, McCauley also incorporates complex explanations of the scientific processes behind the day-to-day maintenance of a celestial settlement. With a strong focus on ecological engineering, *The Quiet War* follows the work of Macy Minnot, whose prowess with building ecosystems from the mud up earns her a place on a ship to the Outer System. Combining the fields of biology, chemistry, and geology, Macy oversees the production of a "mixed culture of bacteria, blue-green algae and diatoms that would clarify the lake water by attaching to suspended fines and elaborating mucopolysaccharide threads to form fluffy accretions heavy enough to sink out of the water column" (McAuley 40). Her contributions help create healthy, organic-rich mud to fill the man-made lake in the new biome on Callisto. Projects such as this are prevalent throughout the Outer System, filled with self-sustaining, closed-cycle

ecosystem domes that depend upon their healthy ecosystems in order to produce the food needed to support the population.

From exploiting large-scale mechanisms of terraforming for planting crops to manufacturing ecosystems from mud and bacteria up, humans rely upon a combination of technological ingenuity, scientific prowess, and knowledge of local geology to maintain their food supplies.

Mining

Since the expense of sending materials from Earth into outer space increases with every gram, the ability to acquire needed materials from other planetary bodies is crucial. Mining these resources from other planets, comets, moons, and asteroids is one solution. In some of these works, mining for profit is an end in itself, while in others mining serves a more societal function of supplementing the supplies for a habitat stationed on another celestial body. With the former purpose in mind, some of Earth's inhabitants from *Heart of the Comet* sought to exploit rocky asteroids and moons for their rare metals, but lacked volatiles such as water, required "for propellants and for biospheres" (Brin and Benford 40). On Halley's Comet, mining for deuterium, a stable isotope of hydrogen used in fusion and fission reactors, provides a steady source of energy for the science base.

Similarly, in *Green Mars*, robots and AIs extract deuterium from heavy water on the asteroid New Clarke (Robinson 67). Not only does mining contribute to these operations' energy requirements, but it also can assist with the physics of altering orbits and trajectories. The deuterium mined from New Clarke, for example, powered an engine that would "fire crushed rock away from the asteroid at speeds of 200 kilometers a second" in order to nudge the asteroid

closer into Mars' orbit for the construction of a space elevator (Robinson, *Green Mars* 67). A similar concept applies to the trajectory-altering actions of the scientists on Halley's Comet, who mined the comet's primordial iron in order to shoot massive bullets from the comet's surface at an impressive "ten thousand kilometers per second, nearly three percent of the speed of light" (Brin and Benford 348). From simply meeting energy demands to shooting large chunks of rock through the vacuum of space at high speed, mining plays a key role.

While these two novels seem to be in sync regarding these energy- and mining-related ideas, other novels interpret the feasibility of mining certain resources quite differently. In *Green Mars*, a transnational corporation constructs "a continuous shuttle system to harvest nitrogen from the almost pure nitrogen atmosphere of Titan, liquefying it and flying it back to Mars and dumping it in the upper atmosphere" (Robinson 207). This process serves to supplement the terraforming processes intended to thicken Mars' atmosphere. However, *The Quiet War* dismisses such ideas by "the dreamers of the early space age" as unfeasible, and it instead suggests that mining Iapetus' carbonaceous deposits for CHON (Carbon, Hydrogen, Oxygen, and Nitrogen) would be a much easier task (McAuley 382). These conflicting opinions show that although different authors may work from similar data describing planetary bodies, they visualize a variety of different possibilities for meeting similar mining-related needs.

Even though debates on environmental preservation in space raged in the Mars Trilogy, the conflicting public opinion on the matter did not stop some from extracting valuable minerals via strip mining. Showing his tendency to quantify, Robinson lists valuable materials found on Mars: "iron, copper, silver, manganese, aluminum, gold, platinum, titanium, chromium, you name it. Sulfides, oxides, silicates, native metals, you name it. The Great Escarpment has them all" (*Red Mars* 303). In *The Quiet War*, strip mines also play a role, having "processed lunar

regolith for helium-3," which fusion reactors required (McAuley 16). While these two examples make no mention of any aesthetic or moral considerations for tearing open the surface of these planetary bodies in the pursuit of minerals, some reflection does exist. As Nadia, an engineer enthralled with building and development, passes by the clutter strewn across Mars' surface – "the stacks of glass, the round cones of gray gravel, the big mounds of raw regolith next to the cement factory, the small mounds of regolith scattered everywhere else" – she takes note of the destruction and to her surprise experiences shock, as she finds herself beginning to see the devastation as a preservationist would see it (Robinson, *Red Mars* 159). Though often essential and beneficial, mining is not simply a positive way to gain resources; it comes with costs, often disturbing the natural beauty of celestial bodies.

Adding an extra twist to the process of mining, all of the core texts expand upon the simple human-driven mining model to implement other forms of technology, AIs and vacuum organisms in particular. As mentioned previously, operations in the Mars Trilogy often utilized robots and AIs, especially for inconvenient locations such as the asteroid that was pushed into a closer Martian orbit for the second space elevator. In *Heart of the Comet*, "mech mining" operations supplemented human crews for tasks such as digging up and processing cometary metals (Brin and Benford 348). On the planet Ventus, the agents of terraforming supplement human mining operations, sometime intentionally and sometimes by chance. On the one hand, the desals created an underground salt mountain as one of their mysterious terraforming tasks, and humans just happened to find this resource useful and decided to dig a quarry (Schroeder 247). On the other hand, the desals also intentionally engaged in operations explicitly for human benefit, like when they "occasionally set off thermonuclear charges deep in the mountains, or in ocean trenches" in order to concentrate valuable metals or minerals closer to the surface for

humans to mine (Schroeder 335). With their futuristic outlook, these novels envision impressive advancements in humanity's technological capacities that enhance humans' mining capabilities on other celestial bodies.

Again touching upon its ecological theme, *The Quiet War* introduces the intriguing concept of vacuum organisms. Although references to AIs are peppered throughout the novel, this work eschews a focus upon such technologies. Instead, McAuley devotes more attention to descriptions of intriguing vacuum-tolerant organisms, which "grew dense, finely-branched webs deep into the ice, leaching out metals and sequestering them into harvestable nodules" (97). Covering vast amounts of land, these organisms carry out tasks such as accumulating pure graphite to aid in the manufacture of industrial diamonds. These organisms enable more economical extraction of metals from smaller meteorite impacts, small deposits not worth setting up a conventional mining operation to exploit, but feasible when seeded with vacuum organisms (McAuley 97). Unlike the AIs in the other novels, which require little to no human oversight, vacuum organisms are continually subject to genetic tinkering by scientists seeking to improve their efficiency. In the early Outer Settlements, these modifications were crucial: "creating vacuum organisms and improving the yields and varieties of the limited number of conventional food plants had made the difference between survival and failure" (McAuley 98). It makes sense that this technology would have to be more intentional, since unlike AIs, biological creations tend to require more oversight, particularly when expected to exist in the harsh vacuum of small moons. All in all, *The Quiet War* explores a unique facet of the many ways in which mining other planetary bodies could be successfully implemented.

Geology in War and Conflict

The act of obtaining resources from other planetary bodies raises several questions: Who is paying for the acquisition of these resources? To whom do these resources belong? To what extent should the concepts of ownership present on Earth apply to the vast resources outside of Earth? Unsurprisingly, the answers to these questions are often disputed and can lead to conflict, and even to war. In *Red Mars*, for example, the chapters from John Boone's perspective chronicle the transformation of Mars from a scientific settlement into a bustling world awash in mega-corporations seeking to harvest Mars' mineral resources for a depleted Earth's hungry markets. As such ventures become more prevalent on Mars, the amount of conflict and intrigue – including the first murder of the book – swiftly increase. Of course, wars in outer space may occur for a variety of reasons, not just over resource and property conflicts, but one thing is certain: given humanity's past record, conflict of some sort is almost guaranteed, no matter the location. And in myriad ways, from burst aquifers to rocky missiles, planetary geology can play a role in these conflicts.

During the conflicts of *The Quiet War*, the inhabitants of the Outer System, behind the curve in terms of the sophisticated weaponry used by Earth, resorted to the age-old method of "throwing rocks at things." With the slightly more sophisticated twist of self-guidance, "smart rocks" served as a weapon of choice for the besieged tent city of Paris on one of Saturn's moons, Dione (McAuley 298). Similarly, Outer System inhabitants resisting submission to Earth's control also sent a chunk of ice from Ymir toward their foes' base on Phoebe, another of Saturn's moons (McAuley 316). On a somewhat larger scale, a group of Martians unsuccessfully nudged a Trojan asteroid into a catastrophic collision course with Earth (McAuley 11). Though a failure, this attempt resulted in a hydrogen bomb-powered counterattack that destroyed all human

settlements on Mars and strained relations with the Outers. In *Heart of the Comet*, tense relations also result from threats by a faction of the scientists on Halley's Comet, the Percells, to slam the comet into Earth, inflicting an impact crater and potential biological contamination from Halley's life-forms upon the planet (Brin and Benford 394). Unsurprisingly, Earth responded by sending a warhead in an attempt to blow up the comet.

Sharing another common weaponry theme, this time pertaining to explosives, many of the novels' characters plot, scheme, and sometimes even actually implement plans to blow up various planetary bodies or settlements on those bodies. Clearly, using explosives in war is not a new idea, but the settings of outer space and other celestial often complicate the matter. As just mentioned, Earth had sent a weapon with "the equivalent of twenty megatons of blistering energy" to shatter Halley's Comet irreparably and permanently remove the threat of a potential impact with Earth (Brin and Benford 466). While such a catastrophe is averted in *Heart of the Comet*, *Red Mars* details the devastating effects of explosives and rockets when built into a moon. Phobos, destroyed in order to bring down the space elevator tethered to it, broke into pieces and cratered the surface; the attached elevator cable wreaked even more havoc, destroying habitation domes and coming down so hard that it metamorphosed and brecciated rocks on impact (Robinson, *Green Mars* 308). For those in the way, such impacts were deadly.

Another method used in this conflict takes into account the nature of Mars' environment and the fragility of the humans who inhabit its surface. By hyperoxygenating the inside of a dome, creating an environment in which "human skin and flesh were combustible and flammable," and then breaking the dome itself and exposing the inhabitants to Mars' unbreathable atmosphere, attackers ensure that inhabitants of the dome face an inevitable and painful death (Robinson, *Red Mars* 510). Warships sent to Ventus, capable of "reducing the

surface of Ventus to char" and leaving "boiled magma seas" across the face of the planet (Schroeder 670), might have exceeded the brutality of Mars' burst by by eliminating all life on the planet's surface, but luckily this conflict was solved by other means. Still, it is fascinating to contemplate the sheer destructive potential of a weapon that could affect not only the entire biological spectrum on a planet, but also all of the geological features of the planet itself.

Another geological, war-related hazard present in some of these novels is that of flooding. Aside from briefly mentioning the woes of a planet plagued by sea level change and drowning in the consequences of anthropogenic climate change, *The Quiet War* does not utilize flooding as a plot device, nor does *Heart of the Comet*. *Red Mars*, on the other hand, explores the effects of utilizing floodwaters as a weapon. After one rebel group deliberately broke an aquifer, "billions of kilos of regolith" were swept down slope, wiping out a handful of channel-mining towns, doomed by their topographically low locations in the flood's path (Robinson, *Red Mars* 484). Though Earth is the "water world" of the solar system, even a planet like Mars with comparatively sparse water content may still contain water-related dangers. And on Ventus, a water world in another solar system, flooding plays a dangerous but pivotal role in the plot. When a hostile AI attempts to take hold over the planet and threatens to "eat this world" for its resources (Schroeder 726), Jordan's knowledge of the planet's terraforming measures and quick thinking save the day. By opening the floodgates available for draining the desalination stacks during an emergency, Jordan wipes out the hostile force under the "white wall" of water that races down the valley (Schroeder 743).

As tools in a conflict, a combined knowledge of a celestial body's planetary geology and the nearby technological resources gives several characters an edge. Macy Minnot, arrested on trumped-up charges by agents of Paris' mayor, uses an awareness of her surroundings to take

shelter from enemy fire behind a boulder, takes into consideration the effects of lighter gravity (compared to that of her home planet of Earth) when sneaking down a crevasse, and she attempts to hurry away quickly because she knows that her captors' suits are equipped with infrared (McAuley 283). Though unsuccessful in her escape, she took the best course of action for someone in her situation, and she might have escaped had her old ally with a personal stake in the matter not chased her down so determinedly. Additionally, another escapee, the famous gene wizard Avernus, successfully avoids contact with Sri by leaving her last known location shortly before Sri's arrival. Thanks to the setting, "Callisto's battered, heavily cratered terrain" that "could hide entire armies," plus the lack of satellites in the atmosphere available to track down her location, Avernus narrowly evades Sri's grasp (McAuley 113). The close miss serves to build anticipation for Sri and Avernus' eventual encounter, where they meet on Avernus' terms, not Sri's.

During his various military campaigns on *Ventus*, General Armiger's increasing understanding of the planet's artificially-intelligent terraforming agents shapes his successes in battle. In an earlier battle, a technologically low-tech conflict, Armiger attempts to implement a clever attack that involves "long tubes filled with sulphur" (Schroeder 24) – chemical weapons, essentially. However, while this method successfully slowed his opponents at first, his victory was cut short when the Winds, angry at the interference that the sulphur posed to the terraforming efforts, swept into the battle and killed all but a few participants. Though this method of exploiting a planetary resource for war resulted in failure for Armiger, his comprehension of the Winds' outrage later brought him victory. Using sacks stuffed with "a combination of pitch, oil, wood, offal and metal shavings, designed to produce a good imitation of industrial smog," Armiger sets off his inflammatory load in the enemy's camp, in order to

"whip the Winds into a fury" against his opposition (Schroeder 532). Just as careful observation and scientific awareness aided Macy and Avernus in *The Quiet War*, these qualities also assisted Armiger in attaining his war-stained ends.

Politics and Planetary Geology

Despite the extensive discussion regarding the manifold means by which humans fight and kill each other using planetary geology, war is by no means the only solution to conflicts. Politics also weaves its way into aspects of planetary geology, perhaps more insidiously but often less fatally.

Easily swayed by bribery and flattery, prominent political figures on Mimas present Greater Brazil, the Earth-based opposing force to the Outers, with a permanent base on their Saturnian moon, in addition to permission to conduct expeditions into Saturn's atmosphere. Under the guise of scientific inquiry, but truly "fronting what was really a shock-and-awe demonstration of the latest model of combat singleship" (McAuley 188), Earth sends expert pilots to show the Outers their technological might. Here, insincere interest in planetary geoscience provides cover for an attempt at intimidation. In response, the city at the heart of the resistance – Paris – commissioned and not-so-accidentally leaked a "feasibility study on the possibility of perturbing the orbits of certain short-period comets, echoing the infamous plan by Martian colonists to target Earth with a Trojan asteroid" (McAuley 219). Not yet at war, these two hostile groups communicate via forceful political and symbolic symbols. When Greater Brazil seeks to humble the Outers with their powerful demonstration, the Outers look to frighten Earth's inhabitants in turn, reminding them that space-based guerrilla tactics such as launching comets at Earth can potentially cause just as much destruction as sophisticated weapons systems.

In *Red Mars*, concerns over Mars' geology and mineral resources in particular lie at the heart of a major political conflict, in which diplomacy and persuasion serve as temporary solutions. Many of Mars' original inhabitants, invested in the planet as their home, feared the effects of mass emigration from Earth and massive depletion of Mars' mineral resources for the benefit of Terran transnational corporations. Political groups such as the Reds, who seek to preserve Mars' natural geological state, particularly fear the disastrous effects of investment by transnational corporations that see nothing wrong with strip-mining vast swathes of land. Frank Chalmers, campaigning for these concerned Martians, engineers a workable solution by playing competing interests off each other. In order to stem immigration, he convinces populous nations like China and India to drop their insistence on fixed higher emigration rates for a bigger cut of the profits from transnationals. To convince first-world nations like his own country, the United States of America, to agree, he plays upon the racial fears of their lowest common denominator, who would object to non-Caucasians "taking over" Mars (Robinson, *Red Mars* 393). While this agreement eventually is ignored, for some time it kept the peace between a variety of factions competing for dominance in Martian affairs.

For Ventus, a planet whose people depend upon its constantly-operating terraforming system, relations with the AIs that run the terraforming efforts – the desals and the Winds – can make or break a government. In order to appease the Winds, who do not hesitate to crack down on perceived infractions against the terraforming system's mysterious rules, environmental regulations designed to prevent humans from inadvertently evoking the Winds' wrath are prevalent on Ventus. Some overly-cautious people even object to devices such as steam cars, "for safety's sake" (Schroeder 12). Similar principles apply to the less-fierce but vitally important desals. For example, one inhabitant of the country of Iapysia explains:

> Our people have always believed that we have a silent pact with the desals. All our laws were made to preserve the pact. As far as we can see, the desals will always use the desert to purify water for the continent. What was in the beginning, will be always. So it should be with our laws, our kings and our traditions. (Schroeder 301)

Due to the constant nature of the desals' support, some believe that human society's structure should remain constant in turn. When Queen Galas, who gained power by manipulating the desals into releasing water at her request for the agricultural benefit of her people, proceeded to use her power to alter many longstanding traditions, it is not surprising that Parliament attempted to control and eventually to depose her. In fact, these conservative inclinations, rooted in the actions of the terraforming system, run so strongly and deeply in Iapysia's society that a war erupts due to her unconventional actions.

In *Heart of the Comet*, politically-motivated arguments dominate the many debates regarding the comet's future. The two main factions split along biological lines, with the Orthos, 'normal humans,' on one side, and the genetically-modified Percells on the other. When biological infestations and sickness plague the scientific station, Halley's inhabitants fiercely debate the merits of altering the comet's orbit in various ways. A majority hope to flee back to Earthspace for assistance. Some Percells suggested a suicide mission to Mars to initiate terraforming, arguing: "We spark life anew on a dead world, perhaps. With our deaths we can begin the long process of bringing Mars alive" (Brin and Benford 358). Other Percells, rejecting the unwelcoming attitudes on Earth toward their kind, even suggest becoming a moon of Neptune and then colonizing "the rock and ice of Triton," one of Neptune's moons (Brin and Benford 328). Ortho Arcists, terrified of contaminating the Earth with Halley-Life, form an unlikely alliance with their typical Percell adversaries on that front. After much debate, the

groups settle on a plan to seek quarantine on Mars, but the arguments that ensue reveal many perspectives on the question of how a human-inhabited comet replete with troubles should be altered.

Mixing politics with matters concerning celestial geologies yields mixed results. Sometimes, as in *Red Mars* and *Heart of the Comet*, political maneuvering can stave off a war. But other times, such as in *Ventus*, political beliefs informed by artificial geological processes for terraforming can lead to greater conflict. And in *The Quiet War*, political bravado and threats can heighten tensions and provoke attacks. The diverse settings of various planetary bodies pose new problems for people to work out, either politically or through diplomacy by other means.

Nature's Dangers

In addition to the risks that come with politics and war, natural hazards posed by numerous aspects of planetary geology can also endanger human lives. Leaving the warm, cozy planet on which humans evolved to settle on celestial bodies with much harsher conditions is no easy task. Despite the best efforts of those who design and maintain such habitats, accidents happen, thanks to the inherent risks present in these settings. Including such accidents in a science fiction novel can serve multiple purposes. By drawing attention to the potential dangers of space exploration, science fiction authors can simultaneously inspire readers to devise answers while also offering their own solutions. And in terms of advancing the plot, the inclusion of dramatic scenes driven by disasters of geologic origins serves as a valuable literary device for creating suspense and pulling the reader into the action of the story. These thrilling scenes can also enhance character development by revealing how different individuals act under the pressure to confront these dangers.

A prominent aspect of space exploration – vacuum – can threaten the lives those who inhabit planetary bodies such as moons and comets. Even planets such as Mars, which does have a thin atmosphere, can prove treacherous to vulnerable humans due to factors such as the surface's low pressure and the atmosphere's high concentration of carbon dioxide. Taking the chance to address the challenges of humans on Mars' surface, Robinson explains how flexible "walkers" made of elastic mesh serve as an improvement over the typical bulky pressurized spacesuits. As "fail-operational" devices, walkers designate only the hard helmet as an airtight space, so that tears in other portions of the suit would only damage the skin beneath, as opposed to risking the occupant's suffocation and death upon minimal exposure (Robinson, *Red Mars* 101). While the Martian atmosphere is fatal for unprotected humans, Robinson's walkers are one example of human creativity and innovation in the face of such planetary atmospheric hazards.

In addition to showing how people address the hazards of hostile extraterrestrial environments, vacuum's role as an ever-present danger also serves to drive character development and increase suspense. In the Mars Trilogy, one Earth-born visitor to Mars observes "the bare fact of Mars, immense and stony, seeming to exert a kind of vacuum pull on him through the window. And in fact if the windowpane were to break the pressure blowout would certainly suck him immediately into that space; an unlikely eventuality, but the image still gave him an unpleasant thrill" (Robinson, *Green Mars* 100). The possibility of a blowout is no idle threat – the many deaths in domed cities such as Nicosia during the revolution demonstrated the dangers of even short exposure to the atmosphere. Though these deaths were caused by willful destruction, an accidental depressurization would prove to be just as fatal. Art Randolph, the observant visitor, continually had such incidents in the back of his mind, as he avoided the windowed side of the room and kept the blinds closed after he imagined the blowout (Robinson,

Green Mars 100). Along with tackling the dangerous task of making contact with and spying upon the hidden "First Hundred" colonists and the Martian Underground, groups that do not wish to be found, Art must also face the potential perils of the planet itself. His hyper-awareness of Mars' physical dangers highlights the stress that he must be feeling about not only relocating to a strange new environment, but also undertaking a clandestine mission.

Similar to the domes from the Mars Trilogy, habitats on the outer planets' moons in *The Quiet War* remain vulnerable to disasters. In Paris, a dome on Dione, some concerned citizens carry oxygen tanks in order to give themselves time to reach safety in an emergency, but such efforts would likely be futile in the event of "explosive decompression" (McAuley 312). Vacuum and explosions also threaten the scientists from *Heart of the Comet*, since the carbon dioxide and amorphous snow present on the comet have the potential to vaporize explosively when exposed to vacuum. For this reason, the scientists do not use ice for cooling directly; as Carl wryly reflects, "It wasn't a snap to use volatiles in high vacuum" (Brin and Benford 66). A brief mention of previous mishaps of this nature on another mission to the comet Encke shows how some problems slip through the cracks, only to be exposed through trial-and-error, sometimes with disastrous results. The allusion to old dangers heightens the sense of tension for the new mission on Halley's Comet, as does the practice of frightened citizens carrying oxygen tanks in *The Quiet War*.

Compounding the problems posed by vacuum, radiation also raises serious safety concerns. While Earth's atmosphere helps block harmful ultraviolet rays, outer space and planetary bodies with thin atmospheres offer no such protection. The core texts offer different approaches to this problem, all with the goal of creating barriers against these harmful DNA-damaging rays. The inhabitants of Halley's Comet utilize the natural resource of the cometary

ice itself, using a kilometer of this material as a protective layer against "the fatal sting of cosmic rays and the sleeting solar storms" for "sleepers" in hibernation until their work shifts begin (Brin and Benford 29). In *The Quiet War*, however, technological innovations such as "layers of fullerene composite and aerogel" help stem the tide of radiation, although simpler methods using local resources such as "meters of stony material, excavated from a nearby crater" also contribute to the protective measures (McAuley 140). On the journey from Earth in *Red Mars*, the First Hundred retreat to a "storm shelter" surrounded by tanks filled with water and heavy metals that filter some of the radiation resulting from solar flares (Robinson 30). Even with this protection, the crew takes about six rem of radiation, which is not ideal for a three-hour exposure time, but they at least escape the 140 rem lethal dose outside the shelter (Robinson, *Red Mars* 64). Based on their available resources, the characters in these stories do what they can to fortify their habitats against the invisible but potentially deadly force of radiation.

Unlike the other core texts, *Ventus* neglects to describe issues such as radiation exposure. Having constructed a plot centering on the mysteries of Ventus' AIs and the struggle against the malevolent AI 3340, Schroeder seems to have chosen to ignore such distractions. In a universe where a fleet of tiny AIs can terraform an entire world on their own, and one massive AI can consume "the skies and earth" on a "progressively more toxic planet" (Schroeder 282), technological mastery of small problems such as radiation exposure can almost certainly be considered a given.

In *Ventus*, the danger and the scientific content both lie mostly within the world-building aspects of the story, not in the plot or in small-scale scientific challenges; instead, complex human creations gone awry serve as the threats, but the AIs are also sometimes the saviors. Many AIs have an interest in planetary bodies – sometimes just for their resources, in the case of

the moons "eaten by the Swans" for use in terraforming Ventus, or the planets consumed by 3340 for its warlike ends (Schroeder 497). However, some AIs take interest in planetary bodies with an eye for their improvement, such as the terraforming and maintenance of Ventus' artificial ecological system:

> The climate of Ventus would never achieve equilibrium; without the constant intervention of the planet's ruling spirits, the air would cool and the oxygen/carbon cycles oscillate out of control. The world would experience alternate phases of hyperoxygenation and asphyxiation, coupled with disastrous atmospheric circulation locks; parts of the globe would be under almost constant rain, others would never receive rain at all. (Schroeder 317)

This passage succinctly illustrates the immensity of the tasks faced by the terraforming agents, as well as emphasizing the importance of their continued efforts for the perpetuation of life on the planet. On the other hand, these creators of life-sustaining conditions on Ventus do not hesitate to take lives away, harnessing their powers to remove threats with methods such as directed lightning bolts. And 3340, indifferent to life on Ventus, immediately begins "harvesting minerals and ores from the rocky terrain around it" (Schroeder 725) in order to build warships to carry out its campaign for power. From manipulating the distribution of salt, to managing atmospheric conditions, to tapping the planetary magnetic field for power, AIs assert their will upon celestial bodies, becoming a danger both in terms of the vital necessity of their terraforming maintenance and the sheer amount of power they can harness against their enemies.

While some hazards of celestial bodies remain unseen, such as the aforementioned dangers of vacuum, radiation, and a cessation of AI interference in the terraforming process, others can be quite apparent to the average observer. For example, the quakes that rocked

Halley's Comet with increasing frequency as the comet approached the sun were hard for the comet's inhabitants to ignore, particularly when they split walls open (Brin and Benford 377). While some quakes only produce easily-ignored mild tremors, others pose a real danger to the scientists. One Halley quake puts Saul in mortal peril: "The ripples arrived and suddenly it was as if he were trying to ride a furry snake, one that bucked and slithered and threw him back and forth" (Brin and Benford 382). Dodging rocks falling from above in the tunnel, Saul quickly runs out of luck and sustains a concussion after taking a rock to the head. On this small planetary body, quakes can have a big impact.

On Mars, by contrast, quakes merit little mention or concern. In *Red Mars*, the brickmaker Gene expresses doubt that the tensile strength of the bricks was high enough to prevent failure in the event of "a little marsquake," prompting Nadia to suggest using shredded nylon from the parachutes to make their structures more resistant (Robinson 113). While this small mention of marsquakes helps to develop Nadia's character as an innovative thinker, it does not particularly progress the plot or build suspense. In terms of naturally-occurring quakes, *Heart of the Comet* takes a dramatic approach, using a tremor to demonstrate one of the dangers faced by a main character, whereas quakes play a much smaller role more related to character development in *Red Mars*.

Natural hazards such as radiation and quakes can cause plenty of problems for space-going explorers, but when humans interfere with natural processes on a celestial body, the problems may become compounded. Quakes caused by a comet's approach to the sun, with "patches of amorphous ice suddenly changing state, exploding off the surface, blowing dust, rocks, boulders into space in great clouds of vapor" (Brin and Benford 440), are one significant but inevitable problem, but the icequakes caused by thermonuclear detonations deep

underground in *Green Mars* constitute an anthropogenic aspect of Mars' hazards. By melting such a large volume of water and pumping it to the surface, the scientists and engineers in charge of this project expose others to dangers relating to the quakes and floods "nearly as vast as the great outbursts of '61" that result (Robinson, *Green Mars* 507). It could be argued, perhaps by preservationist groups like the Reds, that these meddlers bring such consequences down on themselves. These massive terraforming methods bring not only physical dangers, but also risk political consequences from the fallout of any disasters that may occur.

These human-enhanced hazards do not simply exist as hypotheticals; incidents such as Frank Chalmers' death in a flash flood have a profound effect on the story of the Mars Trilogy and upon the characters affected by his demise. Without the changes brought about by terraforming, from the pumping of water to the surface to the heating of the atmosphere, such a massive flood on the surface would not have been possible at that point in Mars' geologic history. Frank's final words before being swept away by the surge – "Go, idiot, go!" – haunt Ann Clayborne, already depressive by nature and upset by the massive volumes of ice on the surface, which "would melt eventually, carve new streambeds and carry her Mars away" (Robinson, *Red Mars* 565). Her feelings of responsibility for his death, in addition to her sorrow at the irreversible alteration of Mars' surface, contribute to her decision to attempt suicide. While Simon fortunately comes to Ann's rescue, victims such as Frank Chalmers, and even non-human victims like Mars' surface, are wiped out of existence by these human-enhanced hazards.

In *Heart of the Comet*, human activity also contributes to fatal accidents, but these incidents result from a smaller scale of activity, less likely to be perceived as humans "playing God" and instead merely a result of people trying to survive in a harsh, unfamiliar environment. One worker, Kato, perishes when a fault under a piece of machinery gives way, as a result of

hollows under the ice creating passages for hot gas from the digging to reach the surface and undermine the anchoring of the equipment (Brin and Benford 6). Another crew member, Umolanda, dies after an iron-bearing boulder explodes into the vapor phase due to the decrease in pressure caused by tunnel excavation (Brin and Benford 8). The process of hollowing out tunnels and chambers under the ice, where the comet's inhabitants take shelter from harmful solar rays, exposes even more hazards in the short term in order to prevent the long-term effects of radiation exposure. These examples show that even with careful planning and foresight, some dangers are unanticipated and unavoidable, part of the inevitable risks of exploration.

The massive dust storms in *Red Mars* also demonstrate short-term dangers caused by planning for beneficial long-term results. Dust storms occurred on Mars before humans arrived, and the ones that occurred in the early days on colonization put those who strayed too far from their home base in tight situations. Afloat in a dirigible with her partner Arkady, Nadia hears the news about an upcoming dust storm and frets:

> Something in the expression on Arkady's face—not fear, not even anxiety, but a curious little *smile*—made her aware of how much danger they were in. If they couldn't use the props, they wouldn't be able to direct their movement, and they might not even be able to stay aloft. They could descend, it was true, and try to anchor; but they had only a few weeks' more food, and storms like these often persisted for two months, sometimes three. (Robinson, *Red Mars* 195)

A dust storm would inconvenience any traveler, but for anyone traveling in a zeppelin, the high winds and lack of visibility bring additional concerns. In the scene above, the tension is palpable as Nadia and Arkady scramble to survive when cut off from their base with only limited supplies on hand. Though dire, storms like the one that caught Nadia and Arkady by surprise appear as

trifles once humans begin terraforming in earnest. A prominent example, dubbed "the Great Storm," lasts for over three Earth years, blocking much of the sunlight needed to grow food and creating hassles such as a preponderance of dust throughout the settlements (Robinson, *Red Mars* 321). Many Martian scientists believe that this enormous storm developed due to changes engendered by the terraforming process. While factors such as a thicker atmosphere protect them from solar radiation and eventually will support a breathable surface environment for humans, hazardous obstacles such as dust storms initially get in the way of improving the planet's livability.

Outlasting the occasional dust storms of Mars, Saturn's atmospheric storms occur frequently, and "Great White Spots" an order of magnitude larger than normal storms happen about once every 30 years (Sánchez-Lavega et al. 71). The dangers associated with these storms do not crop up due to conflicts in short-term and long-term priorities, but instead occur as a result of human daring in the face of new challenges. As a gas planet, Saturn itself does not offer a hospitable environment for settlement, but such trifles cannot stop those who are adventurous – or perhaps foolish – enough to zip down into its atmosphere in a space ship. *The Quiet War* describes the descent of two pilots, Cash Baker and Vera Jackson, into the liquid-water zone of Saturn's atmosphere. While carrying out his maneuver, Cash reflects upon "the amorphous boundary between the gaseous atmosphere and the deep ocean of hot metallic hydrogen that lay beneath," an area with such high temperatures and pressures that in the event of a mechanical failure that prevented departure from the planet's depths, a ship like his would be destroyed long before reaching this zone (McAuley 201). Although they must face such uncertainties and encounter "bone-shaking turbulence" (McAuley 203), Cash and Vera simply whisk right ahead into their next tasks. Their confidence conveys the immensity of their society's technological

accomplishments; although not on the level of the planet-altering AIs or mecha in *Ventus*, *The Quiet War*'s technology enables amazing feats such as humans dipping deep into Saturn's atmosphere with little regard for the dangers.

Though he survived hurtling through the winds of Saturn in a singleship, Cash Baker's confidence in his technology, or at least his command of his machinery, turns out to be sorely misplaced. The unfortunate soldier dies in the rings of the very planet that he was first to explore so deeply. When he loses control of his ship and crosses at a low angle through the plane of Saturn's ring, "more than a quarter of a million kilometers across but just ten metres thick," a miniscule piece of debris smashes through the ship and enters his brain (McAuley 378). Cash meets his end by colliding with "a speck of basalt, less than a millimetre in diameter, polished and eroded by billions of years of microscopic collisions" (McAuley 378). The text emphasizes the smallness of the rock fragment and the length of its time harmlessly floating in space. Who would expect that such a tiny, seemingly-harmless object, floating for eons within the rings of a gas planet millions of miles from Earth, would cause a human life to end? With this passage, McAuley details the potentially fatal dangers that even an insignificant rock can prove to possess.

Small rock particles also create a hazard in *Heart of the Comet*, where sublimation of the comet's ice into the gas phase causes dust pebbles on the surface to be "blasted outward" (Brin and Benford 87). However, this hazard only manifests itself during the cometary summer, when Halley passes near the sun. After traveling far enough away, precautions such as heavy armor on the workers' spacesuits are no longer necessary. However, other dangers endemic to the comet continually threaten its inhabitants. Due to a technical issue with a tunnel's cooling vent, melting ice creates a tight situation when "a block of dark, mottled crystal pierced through the fibersheath

lining and smashed the side of the shaft" (Brin and Benford 216). Two crew members die in the ordeal. And as Saul notes, "if any of their suits had been punctured, even the blood cyanutes wouldn't have protected the trapped crewmen much longer from the rich vein of cyanide that had been broken open by the falling rock" (Brin and Benford 216). Not only do the workers need to worry about falling ice blocks, but they must also consider the dangerous compounds that might lie concealed under the ice, one break away from poisoning an exposed crew member. In the face of all of these hazards, though, Saul still manages to suppress his survival instincts and pauses to take a sample of the organism that caused the cooling vent malfunction. Saul's seemingly irrational behavior in a dangerous situation speaks to his strong sense of curiosity and scientific drive to discover the reason why this tragic event occurred. With this almost-comical diversion from an otherwise intense scene, Brin and Bedford demonstrate Saul's dedication to learning.

The natural hazards of planetary geology run the gamut in these stories, from the imperceptible dangers of vacuum and radiation to particularly-apparent dangers such as quakes and floods and dust storms. Expansive concerns regarding the delicate balance maintained by Ventus' AIs loom for an entire world's population, while the threat posed by a single speck of rock has an effect on an individual level. This profusion of potential problems serves a variety of purposes. Through exposition of the solutions, such as the fail-resistant walkers in *Red Mars*, authors can present their ideas for countering the obstacles of space exploration. Moreover, broaching the subject of these hazards in the first place may inspire readers to come up with their own solutions to these problems. Additionally, injecting action into a novel can pull the reader into the story; hair-raising descriptions such as a Halley quake's "shrieking noise, like giant stones rubbing against each other" (Brin and Benford 382), leave the reader anxious to learn more. Putting characters in jeopardy also can promote character development, revealing how

different individuals react to these perilous situations. All things considered, the dangers of planetary environments play a key role in shaping these hard science fiction novels.

Making Connections to Science

The previous sections have explored the relationships between the geology of different planetary bodies and the humans who encounter it. One idea that has been touched upon thus far, but merits more attention, is the accuracy and involvement of the science present in these novels. With the inclusion of scientists as characters and the incorporation of scientific experiments and the scientific method, the scientific foundations of the novel can be strengthened. Furthermore, an important aspect of hard science fiction, distinguishing it from fantasy, is the integration of real science into the stories. Using this existing data as a basis, authors can make fairly realistic predictions about the future state of scientific knowledge and how that in turn will impact humans in the future. The connections to science itself as a discipline can serve as a vehicle for educating the reader about the many fascinating areas of scientific study that exist, planetary geology in particular.

Scientists in the Novels

As hard science fiction novels, it is not surprising that the core texts all contain at least one character who could be considered a scientist. Sri, a prominent researcher at the top of her field in *The Quiet War*, lives and breathes science, involving herself in politics only as a means to advance her research-related aims. She manages a research base on the moon and takes pride in her scientific accomplishments, such as "developing an artificial photosynthetic system that was almost five percent more efficient than any designed by Avernus" (McAuley 98). Her obsession with finding and collaborating with the mysterious yet renowned Avernus prompts Sri to travel from Earth to Saturn, and her initial failure to make contact only invigorates Sri's "determination to prove herself a match for the woman's powers, or even surpass her" (McAuley

129). Sri's motives for her research may not always be purely grounded in scientific curiosity, as such competitive comments reveal, but Sri does also appear to possess true passion for scientific discovery. She chastises the older generation of Outers for lacking "energy and spirit and vision" in their research, which she derides as "hobbyist" at best for not producing anything more novel than tweaks of previous accomplishments (McAuley 100). Though normally obligated to promote her superiors' interests and spout pro-Earth propaganda, Sri realizes during her argument with the Outers that "she really and truly believed it" (McAuley 100); though the Outers had made great scientific advances in the past, Sri truly believes that Earth now holds the most promise for scientific progress.

Also seeking scientific progress, the crew of *Heart of the Comet* consists primarily of scientists and technicians. In an address to the crew, Captain Cruz proclaims, "Philosophers speak of pure scientific research, of the great questions of the origin of the solar system which might be solved by understanding the most primordial matter in space" (Brin and Benford 75). From the very conception of this mission, an optimistic vision of the great returns of cometary research buoys the spirits of the scientists and investors alike. Virginia, a scientist deeply involved in researching bio-organic computing herself, remarks, "Space is saving humanity. Even reactionaries and Arcists know that. Why do you think Hawaii invested so heavily in this expedition?" (Brin and Benford 89). Saul, another scientist aboard who devotes hours upon hours to conducting research, bears a resemblance to Sri from *The Quiet War* in terms of his dedication to making new discoveries. He works so hard that his friends rib him about the amount of time he spends fine-tuning his work in the lab. Saul also displays an inquisitive nature through his many questions, especially after the crew finds alien life-forms on the comet: "Where did Halley-Life come from? Did comets seed the Earth, long ago? Or are we only the

latest invaders of this little worldlet? How could all of this have happened in the first place?" (Brin and Benford 301). This line of inquiry demonstrates Saul's scientific outlook, and such questions weigh on his mind throughout his story.

Like *Heart of the Comet*, *Red Mars* also begins with a scientific mission full of inquiring minds. Yet again, dedication to their research consumes the lives of many scientists. Fearing the erasure of Mars' native landscape almost from the beginning, geologist Ann Clayborne works herself to exhaustion trying to document as much of the planet as possible; her friend Nadia observes, "Ann looked nearly asleep; she was spending her mornings taking long rover trips and hikes, and then working hard on the base all afternoon, trying to make up for her trips away" (Robinson, *Red Mars* 107). For Ann's opponent in the terraforming debate, Sax Russell, the scientific study of the world around him serves as a driving force in his life. When he was a child, he desired to know the "why" of everything, and in adulthood, he conceives of science as "a system for generating answers" for one simple purpose: "to know" (Robinson, *Green Mars* 401). Strangely enough, although these two scientists spent much of their lives as bitter enemies, their similar passions – for science, for Mars, for each other – win out in the end, and the two become a couple.

At the beginning of *Ventus*, two tiers of understanding about the universe and its processes initially exist. Privileged individuals such as Axel and Caladria have access to amazing technologies, while the inhabitants of Ventus live in a world of comparatively primitive technology, thanks to the Winds. Although members of the latter group, such as Queen Galas, have fewer means to accomplish their quest for answers, scientific progress and inquiry remain possible. Galas, for example, leads an expedition in which she and other scientists sought to use

seismographs to detect and measure thermonuclear charges "deep in the mountains, or in ocean trenches" set off by AIs in order to direct precious metals toward the surface (Schroeder 335). Although he already possesses many of the answers to Galas' questions, Armiger seems impressed by her tenacious inquisitiveness and declares, "You want to interrogate the sky. And you of all people, Queen Galas, would interrogate nature itself, everything that is *other*, in your human search for understanding. Everything you have ever done proves this" (Schroeder 267). Similar to Sax, Queen Galas seeks to wrench answers to her questions from any source possible. Her desire to comprehend the universe is reflected in all of her actions, as Armiger notes. Galas' efforts at understanding reflect the nature of science as a means for obtaining truths about the universe and how it works.

Experiments and the Scientific Method

In addition to including scientists as characters, these novels also involve many scientific experiments and examples of the scientific method in action. In *Heart of the Comet*, Virginia commences a "grand experiment" of altering Halley's orbit by slowing down the comet's spin and strategically blocking certain areas of ice with silicate shields in order to direct the comet's outgassing (Brin and Benford 465). Based on her models and calculations, which projected only mediocre odds of success, Virginia tests her ability to alter the comet's orbit out of necessity, in order to direct the comet to safety. Likewise, Saul feverishly experiments in the lab to determine the cause of the sicknesses spreading through the crew. Although they started with idealistic intentions of conducting pure research, Halley's scientists often find the direction of their experiments leaning to immediately useful applications in the face of multiple crises.

In *Ventus*, on the other hand, most scientific research seems to be done for pleasure. Marya Mounce, a cultural anthropologist living on a research vessel in Ventus' orbit, proudly lists her accomplishments after landing on the surface: "I know Ventus like the back of my hand … I know the history. I know the geography, every city and hamlet on this continent. I speak six local languages, without the need for implant dictionaries. I've studied the religions twelve different ways" (Schroeder 417). Clearly, this social scientist studies Ventus due to her passion for the planet and its people. Similarly, as a member of the royal family, Galas could have spent her time any way she pleased, but she chose to go on a research mission to investigate seismological processes on the planet. From frantically solving pressing problems to leisurely seeking geophysical data on a sailing expedition, characters allow scientific experiments to play a significant role in their lives. In addition to preoccupying such scientists, these experiments further serve to reveal facts and lessons about planetary geology or other sciences to the reader.

The experiments in *The Quiet War* play a vital role, but are less urgent than those in *Heart of the Comet*. As part of her work for the new biome on Callisto, Macy investigates a minor problem with the plankton population in the dome by making plans to "run some simple experiments to check the diatom's phosphate uptake system and investigate nutrient binding in the melt water" (McAuley 64). Although these tiny organisms occupy a critical niche in the habitat, their issues do not immediately threaten the lives of the dome's inhabitants, so Macy also has time to accomplish other basic tasks along with addressing the problem. Similarly, with the abundance of other viable methods for producing food inside of tented domes and greenhouses, the Vishniac labs scientists in *Blue Mars* attempting to accelerate topsoil development on Mars' surface are conducting important but non-imperative research. Robinson describes the general approach to the problem, involving "factorial trials, altering the conditions in each pedon and

tracking what happened," in addition to defining the equation for soil properties and delving into the complexities of the different conditions and factors that could be altered, from pH levels to salinities to compaction (*Blue Mars* 331). In and of themselves, these experiments do not particularly progress the story plotwise, but they do add an intriguing layer of depth, educating the reader about a specific topic like soil science and showing various applications of science in tackling research problems on other celestial bodies.

Whether sf authors incorporate science into the character, the plot, or both, such inclusions facilitate the "hard sf" emphasis on incorporating real science into the stories. These scientists may embody the stereotypical research-driven image of the modern scientist, paint a picture of a fun-loving science enthusiast, or even break the mold and expose their identity as scientists through their systematic questioning, even if they lack an official designation as a career scientist. Similarly, scientific experiments included in the novels have a wide range. From urgently necessary life-saving experimental methods to unhurried studies conducted simply for the sake of learning to science that falls somewhere in between, scientific experiments show the science behind the endeavors of the characters, whether they are creating soil on Mars or steering the trajectory of a comet. Through explanations of such experiments, sf authors can convey the details of the planetary geology or other scientific disciplines involved, informing the readers and enriching their stories.

Exploring and Evaluating Connections to Published Science

Projecting their own unique predictions into imagined future worlds, hard sf novelists strive not only to create fantastic stories, settings, and characters, but also to blend science into the mix. In some instances, an abundance of data and publications exist from which sf authors

can draw to supplement their stories. In other cases a dearth of information about other celestial bodies is available; for unanswered topics, such as the possibility of extraterrestrial organisms dwelling beneath Europa's ice, authors can only conjecture. However, sf authors can use the data that is available for a celestial body to explore a viable avenue of probability and extrapolate upon it. Although nobody may truly know for certain the facts of the matter, sf authors can create plausible hypothetical situations drawing from known information that may support the author's proposed scenario. Throughout this following section, a sampling of the many instances of planetary geology in the core texts has been selected in order to illustrate the connections to established scientific knowledge. With these examples, this study will examine the extent to which the authors are essentially reporting upon the state of knowledge in the area versus extrapolating forward based on the possibilities that a greater knowledge of planetary geology might impart.

As previously mentioned, the topic of life in Europa's ocean crops up as a minor point of interest in *The Quiet War*. McCauley describes the few "rich oases of life" near hydrothermal rifts within "the vast and lightless deserts of Europa's ocean" (123), which supports life only in the few areas that release heat and water "rich in minerals and hydrogen sulphide" out of the cracks (122). McCauley's decision to depict extraterrestrial life on Europa, described as "the most promising place in the solar system for astrobiological potential" by a planetary scientist at NASA's Jet Propulsion Laboratory, Robert Pappalardo, appears to be a perfect example of fiction rooted in science (Ksanfomality 757). Covered in an exterior of solid ice, Europa has prompted experts to speculate whether or not the moon contains liquid water beneath its surface; evidence such as a visible "network of intersecting lines representing faults and crevices of the ice shell," resembling the Arctic Ocean's ice field morphology, lend support to the liquid water

theory (Ksanfomality 757). Additionally, the lack of craters on the surface may indicate that liquid water filled the voids on the surface geologically recently, and thick ice could shield potential life forms from radiation (Lawler). McCauley's example of alien life falls within the bounds of these models of Europa, and his illustration of vent microbes reliant upon sulphur from underwater vents meshes well with Earth-based analogs of "sulfur-feeding bacteria" that "flourish at the darkest depths of the oceans" (Lawler). Another study concluded that "most every physiological stress can be overcome so long as the environment contains liquid water," another good sign for extraterrestrial life on Europa (Kargel et al. 256). Ultimately, an abundance of evidence exists to support the possibility of life on Europa, and McCauley seems to have carefully considered and implemented such knowledge for his imagined life forms in *The Quiet War*.

Another topic drawing from a combination of scientific data and speculation, one which appears throughout the core texts, is the possibility of harvesting comets. The composition of comets, which includes elements essential to life such as carbon and nitrogen, plus the fact that comets are approximately 30 percent water by mass, makes these celestial bodies an important resource (Greenberg 375). Comets play a key role in Ventus' early terraforming stages; AIs called Swans spend decades organizing the harvest of comets to supplement Ventus' naturally thin atmosphere (Schroeder 497). Some scientists from *Heart of the Comet* also promote comets as a vehicle to "spark life anew on a dead world" like Mars, building up an atmosphere to make the planet more suitable for human habitation (Brin and Benford 358). Given that some models suggest that the atmospheres of planetary bodies such as Earth and Titan originated from cometary impacts (Trigo-Rodriguez and Martin-Torres 8), the extension of this natural process into the realm of artificially-created atmospheres via comets is not a far stretch.

Blue Mars, however, brings up a potential risk of using such methods; a poorly-directed impact could send water blasting back out into space, resulting in a net loss of water in the process (Robinson 489). Several studies express similar trepidation; for instance, McKay and Marinova question whether an asteroid or comet aimed at Mars would "contribute its volatiles to the martian atmosphere" or "cause a net removal of mass due to the impact explosion" (94). Luckily for would-be terraformers, *Green Mars* proposes a method to address such concerns. By blowing up projectiles, in this case asteroids, as they enter the atmosphere, the risks of volatiles blasting back out of the atmosphere are abated, while the benefits of thickening the atmosphere are promoted (Robinson, *Green Mars* 51). This example demonstrates the ongoing process in both science and science fiction of proposing ideas to the community at large, which often responds with criticisms and solutions of its own.

Some novels go into great detail regarding the mechanics of topics like terraforming, while others only provide a short commentary. Both methods have their own merits and pitfalls. Short mentions may tantalize the reader with a snapshot of a concept, but such brevity may prove frustrating to some. On the other hand, extensive descriptions of scientific problems provide a clearer picture of the topic, but such long passages may distract from the main storyline or cause some readers to lose interest. Continuing with the example of terraforming, *The Quiet War* briefly mentions the increase in atmospheric pressure resulting from a cometary impact on Mars. The novel's overall description of an optimistic vision for terraforming Mars sums up the idea nicely and succinctly; using Jovian moons, terraformers would transport "thousands of tons of halocarbon greenhouse gases that would significantly warm the planet and cause outgassing of carbon dioxide and water vapour from the frozen regolith" (McAuley 105). In just a few lines, a whole world of possibility can be imagined.

The Mars Trilogy provides a much more comprehensive view of the terraforming process. Set within a presentation at a large Martian academic conference, the atmospheric terraforming results are laid out by category of the driving force, such as the two most effective methods of adding "Halocarbons" or "H_2O and CO_2" to the atmosphere, with the amount of additional heat in degrees Kelvin listed beside the method (Robinson, *Green Mars* 206). Described by one article as "the most viable technique for warming Mars," greenhouse gases such as halocarbons, water, and carbon dioxide have proven their effectiveness at altering Earth's climate, so their application to Mars seems like the next logical step (McKay and Marinova 3). For those truly interested in the prospect of terraforming Mars, Robinson's carefully thought out presentation of the process provides a wealth of well-researched information and speculation on the subject. While different novels approach the incorporation of scientific fact and informed speculation into the story in different ways, both the expansive and limited inclusions can be effectively implemented.

One common theme throughout the core texts is the assumption of technological advance, as opposed to the inevitability of apocalyptic ruin. Innumerable aspects of these stories presume the existence of technological abilities yet to be developed, from the simple act of safely transporting humans to other planets to the massive processes of disassembling moons and redirecting comets to terraform planets. For instance, marveling at the massive tent planned to cover the kilometer-long Hebes Chasma, Sax Russell notes: "One should never underestimate the potential of materials science, that was clear" (Robinson, *Green Mars* 149-150). The astonishment of Robinson's long-lived characters at the changes occurring within their lifetimes reflects the awe that the modern reader might experience upon regarding such marvels. The extensive capabilities of the AIs in *Ventus* evoke similar feelings. This form of wonder, or

"scientific sublime," exists within "a technosphere that surpasses its creators' understanding, making technology both the cause of the sublime shock and the means of recuperation" (Csicsery-Ronay 161). The large scale and amazing results of such AI machinery, which transforms an entire uninhabitable world into an oasis of life, almost defies a person's ability to grasp the magnitude of the changes that have occurred.

Despite these amazing portrayals of sophisticated technological science, though, much of the planetary geology present in these stories remains the same. These authors are not inventing new minerals to mine or trying to discredit the theory of plate tectonics; instead, they incorporate the accumulated knowledge of planetary geology into their stories. For example, although Schroeder invents a fictional planet, he does not overextend his license and make that planet out of nonsensical materials; instead, the world is populated with geological features similar to those found on Earth, such as quartz-grained desert sands, salt flats, archipelagos, and the occasional mountain range. These details cement the reality and enhance the believability of this world.

Of course, not all incorporations of science-related material have purely educational motives. One humorous example of this occurs in *Heart of the Comet*, which, according to Brin, was "the one document on Earth that correctly predicted the size, shape, and composition of Halley's Comet" (Brin). Brin predicted a smaller size for Halley's Comet in his doctoral dissertation, but he overlooked that much of the rock would be black carbonaceous chondrite, and therefore less visible. But in the novel Brin and Bedford expanded the size of the comet with a plot-driven motivation, "in order for it to have enough gravity for characters to run across the surface shooting each other" (Brin). Also with humor in mind, Robinson describes the reactions of biologists Vlad and Ursula to Sax's faulty model, which neglects to consider that "temperature gradients between biotically defrosted soil and the remaining frosted areas would be greater than

ever, and the winds between the two regions correspondingly fiercer; so that when they finally hit loose fines, off they would go," ideas which the two biologists disdainfully declare are "totally obvious" (*Red Mars* 300). The long, complex explanation does not seem like it should be followed by a blithe comment about the problem's simplicity. Laughing, an observing character notes that "scientists could be so catty," further lightening the mood (Robinson, *Red Mars* 300). For the sake of creating an entertaining story, even hard sf authors may modify a few scientific details to better fit their intended plot or inject humor into their works. After all, while these novels may have lofty motives such as education or inspiration, they also aim to provide a pleasant way for the readers to pass the time.

Conclusions

This study used a selection of core texts to investigate the roles that planetary geology can play in hard science fiction novels. These six novels – *Heart of the Comet, Ventus, The Quiet War, Red Mars, Green Mars, and Blue Mars* – reveal the many ways in which planetary geology can be integrated within a text. As a source of inspiration, descriptions of celestial bodies and their geological features can elicit a sense of wonder. Through the interactions of characters and planetary geology, authors can explore the effects of humans upon a celestial body and the effects of that celestial body on humans in turn, topics which often prompt many ethical questions. With connections to technical problems such as terraforming, resource acquisition, and natural hazards, planetary geology can greatly influence the course of a story. Potential connections to politics, war, and conflict entwine planetary geology even more deeply into the plots of these novels. Furthermore, solidifying their identities as hard science fiction works, the inclusion of scientists as characters, examples of scientific experiments and the scientific method, and connections to established planetary science contribute an additional layer of depth to these texts.

Ultimately, planetary geology enriches science fiction literature in countless ways, and works of hard science fiction contribute to the scientific discipline of planetary geology in turn by pushing the envelope of possibility and proposing inspiring new ideas and implementations of the subject into their storylines. Together, the two fields influence each other for the better, driving each other to evolve in new, interesting directions. Publications from one field can provide inspiration for those working in the other. Planetary geology encompasses a wide scope of subject material, incorporating disciplines such as chemistry, biology, and physics. With such versatility, planetary geology can promote scientific thought and enhance the quality of science

fiction literature in myriad ways, while science fiction literature can inspire continued innovation in and passion for planetary geology.

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