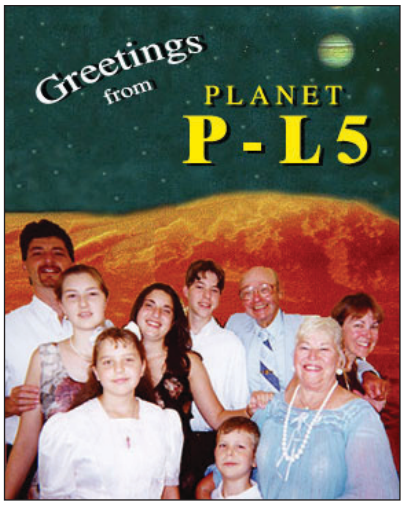
NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Alien Evolution:

The Return of the Cambrian Explosion



by
Shoshana Tobias
University at Buffalo, State University of New York

Part I – A Beautiful Planet?

Jay looked at the seas and land that peeked out from beneath the clouds of P-L5. He was anxious to get home to Earth, but he couldn't help but wonder at this beautiful and mysterious planet. "P-L5," as it was termed, had been home to a small human colony and thriving tourist industry for over a century when the inhabitants had fled to neighboring systems almost 100 years ago. Now Jay and his colleagues would be deciding whether or not a new colony should be attempted there. They didn't have long to decide either; with all the chaos on Earth, nothing was getting much funding these days. Luckily, K&P Securities had offered to sponsor the side trip and a crew had been thrown together. The captain had given them a tantalizing description of the planet they would be investigating:

> *Many of you have heard of P-L5, some of you may even have had family that once lived there. Let it stand as a reminder in your future travels never to underestimate and ignore the environment around you. The earliest record of this planet is from the year 2400 when the Fifth Quadrant was discovered. The description is of a simple beautiful planet ideal for human habitation: moderate oxygen levels around 5%, clear blue seas, and land for building. The only native life was a harmless collection of chemoautotrophs, photoautotrophs, and passive filter feeders. With a few environmental adjustments, the planet was settled in 2460 and became a mecca for tourists and for industry, at one time supporting a water distillation plant, farms, factories, schools, libraries, and research facilities. Then for reasons still unclear, things began to change; the inhabitants fled to new planets, leaving their towns and belongings behind. These ghost towns now stand very much as they were left 100 years ago when people still lived there. This is a two-day stopover. Enjoy the beach, look around, but be careful—we still don't know exactly what happened down there. I will expect a full report in three days detailing environmental and biological conditions on the ground as well as a decision on re-colonization.*

As soon as the little shuttle landed, Jay burst out ready to explore. The first thing that hit him was the fresh air. *Mmmm, oxygen.* The early colonists had probably prepared the planet by pumping oxygen into its atmosphere to raise the O_2 concentration to earth levels, standard procedure back then. He walked towards the cluster of hulking buildings; the iron railings had begun to show signs of rust. He swung open the unlocked doors and stepped into the municipal building. Hopefully he would find a clue to this mystery among the scattered government documents lying about. He picked up a binder marked "water supply." Early water tests had shown high oxygen content, moderate calcium carbonate levels, and low sulfur, nitrogen, and phosphates. Cyanobacteria were also present. Interesting. A memo dated 2480 complained of flat soft-bodied organisms, some up to one meter long, getting jammed in the deep sea intake pipes. Flipping through the entries he came across later notices and complaints: one memo about 50 years later noted tourist complaints about water taste and cloudiness, which the plant manager blamed on phosphate, sulfur, calcium carbonate, and nitrogen runoff from "those damn farms" and years of deep sea dumping by one of the offshore factories. Later reports noted an increase in harder bodied organisms being caught in the sea intakes. Jay pocketed several of the sketches.

It was starting to get dark by then, so Jay decided to take a quick walk to the shore before boarding the shuttle for the night. Walking through the empty streets, he wondered what had happened. Obviously the environmental change had

been rapid, and he had a hunch the alien organisms had probably changed quickly as well. Rapid evolution was not unknown. He remembered once having to move camp every night to avoid a river bed that changed course by morning, or his aunt's flower beds on Pentarch that came up in different shapes and colors every year. It would not surprise him if the change here had been fast—probably catching the colonists unprepared.

His boots crunched along the shore as he scanned the beach. A thin film of dirt had covered the old water intakes in the distance, and the murky water hid its secrets from view. He noticed what appeared to be deep burrows, several inches long, as the waves receded. Interesting. He took out the sketches. The planet's jelly-like, flat-bodied early life could not have made these; they lacked the firmness, strength, and three-dimensional body shape to tunnel. Whatever was living in these burrows was closer to the strange hard-bodied creatures that came later. He bent down to examine the tide pools that foamed around his feet. Maybe the waves had washed something ashore. He scooped up a tiny shelled creature no bigger than his thumb. It looked as if it had been bitten in half, and so had many of the larger life forms he found along the beach. So much for the harmless autotrophs; predation had obviously begun. Drawing a quick sketch of what he had found he ran back to the shuttle, determined to fit together the pieces to this planetary puzzle.

"Hey, Jay," one of his friends called out. "Since when did you start taking evolutionary biology? Nice sketches, but the trilobite looks a little funny."

"You know what these things are?" Jay asked in surprise.

"Sure, look up Earth's Late Precambrian, aka "Vendian" or "Ediacaran" period, and the Cambrian period (543 to 510 million years ago) that came after it. You can use my computer."

"You know, I think I will."

Here's the Situation

You have two days before you and your colleagues must decide the fate of this planet and the hundreds of people who are waiting to re-colonize it. Before you come to any conclusions, however, you need to find out exactly what happened on this planet, why it happened, and what the future possibilities are. You will want to review the following documents that Jay discovered: memo dated 2480, memo dated 2530, and the drawings dated 2660 (see next pages). You will also want to read some sources on Earth's Late Precambrian, also known as the "Vendian" or "Ediacaran" period, and the Cambrian period (543 to 510 million years ago).

By the time you return to class to solve this case, you will need to know:

1. What was the Late Pre-Cambrian environment like on Earth?
2. What were the Ediacaran organisms like and how were they adapted to their environment?
3. How is Earth's Pre-Cambrian similar to P-L5's initial environment and organisms?
4. What was the "Cambrian Explosion"?
5. How did the environment and organisms change and adapt during the "Cambrian Explosion"?
6. What causes led to the "Cambrian Explosion"?
7. Could any of those Earth conditions have been mimicked on P-L5? How?
8. Assuming that this alien planet was going through an Alien "Cambrian Explosion" that mimicked Earth, what do you think will happen next?

Helpful Internet Sites

The Divisions of Precambrian Time: <http://www.ucmp.berkeley.edu/precambrian/precambrian.html>

Life of the Vendian: <http://www.ucmp.berkeley.edu/vendian/vendianlife.html>

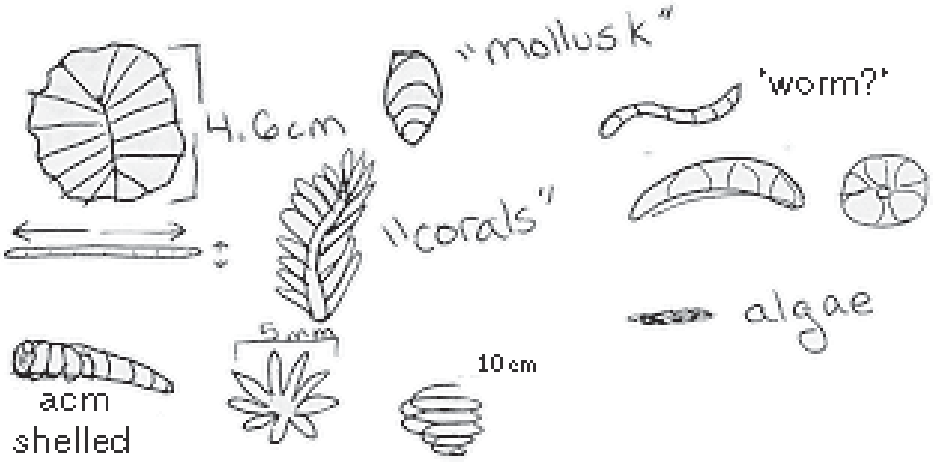
Learning About the Vendian Animals: <http://www.ucmp.berkeley.edu/vendian/critters.html>

Lambert, J. (2019, May 9). Rapid oxygen changes fueled an explosion in ancient animal diversity [webpage]. *Quanta Magazine*. <https://www.quantamagazine.org/rapid-oxygen-changes-fueled-an-explosion-in-ancient-animal-diversity-20190509/>

Date: 2480
MEMO: To: Research Facilities
From: Tim Lazen, Water Plant
RE: Samples

Here are the sketches you wanted. We are sending three guys a week out to keep the pipes clean.

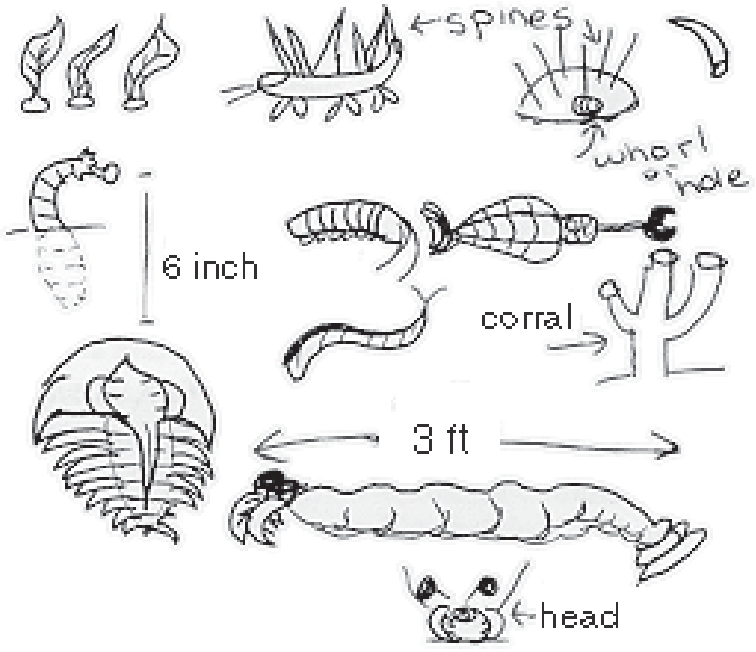
The tourist commission is pushing for more water production and I need this "critter problem" resolved!

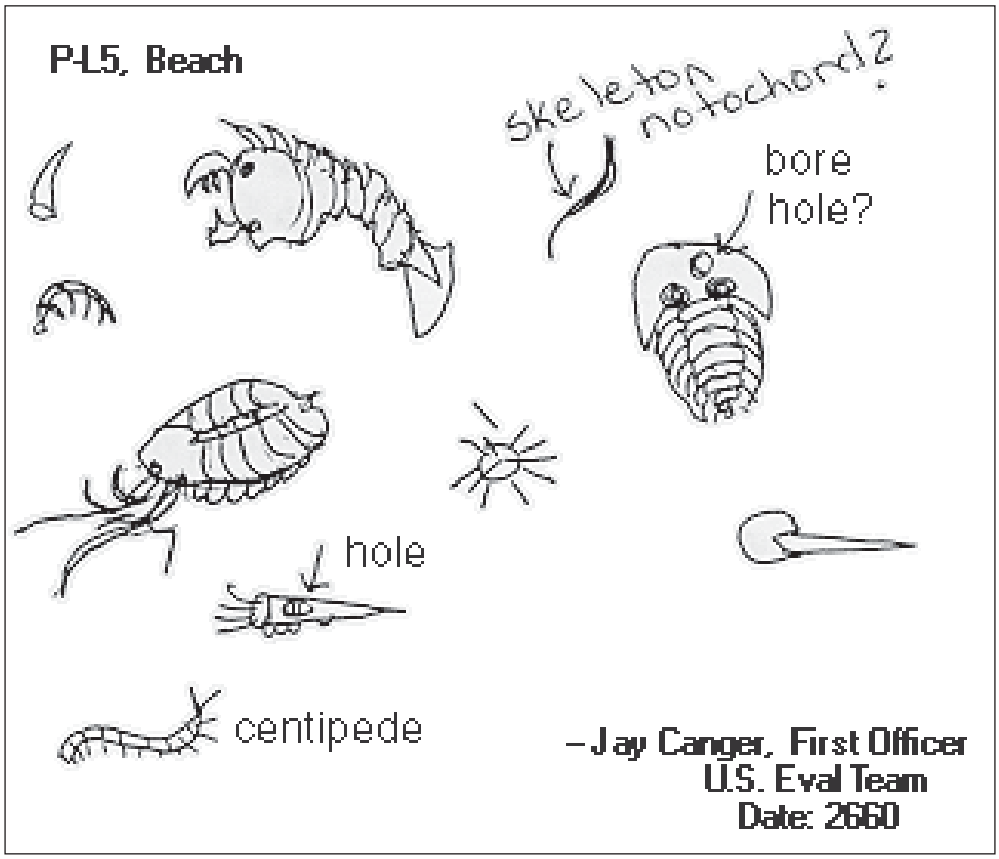


Date: 2530
MEMO: To: K. Ranem, Research Facility
From: Tim Lazen Jr.
RE: Trouble

CONFIDENTIAL

We can't seem to get rid of these new pests. I tried mesh filters on the pipes and they just get clogged. I sent some of the guys out to collect samples in the sub, and one even refused to go down there! Kim, I'm starting to get worried about this. I've had three guys this year come back babbling about monsters and crazy spiked animals. I'm including the sketches they brought back—I'll be damned if you know what they are. Try and keep this quiet though, the tourists are a bit edgy since the last beach incident.




P-L5, Beach
skeleton notochord?
bore hole?
hole
centipede
–Jay Canger, First Officer
U.S. Eval Team
Date: 2660

Part II – Time to Decide

Jay could hardly wait for dinner to end. His mind was racing with a hundred theories and ideas. It had taken the colonists less then 100 years to dramatically change the planet. Could the colonists' planetary "adjustments" have adjusted more than they intended? How had it affected the native creatures? Could the murky water be hiding new animals? Predators perhaps? And why had the people fled? Once at the computer counsel, Jay logged into his old biology book, and what he found shocked him:

> *The Ediacaran Period (also referred to as the Vendian or Late Pre-Cambrian) occurred from approximately 700 million years ago until 543 million years ago Earth time. The period was noted for its simple soft-bodied Ediacaran fauna, mainly autotrophic chemo and photo autotrophs and symbionts as well as filter feeders and passive nutrient absorbers, all inhabiting the deep oceans (see "Burgess Shale"). Oxygen levels were still low (approx. 5%), although cyanobacteria (blue green bacteria) were slowly raising the O_2 concentration. Great environmental and biological changes began that would have far-reaching impact. Massive glaciers dumped tons of sediment rich in nitrogen, sulfides, calcium carbonate, and phosphates into the seas, encouraging new life forms that grazed on the bacteria-covered nutrients, and providing the calcium carbonate and phosphates that would later be used to make shells. The oceanic and atmospheric oxygen concentration reached a threshold, wiping out some life forms while allowing others to raise their metabolic rates and thrive (see "Oxygen Revolution"). The appearance of early predators towards the end of the Pre-Cambrian signaled the shift in feeding styles from autotrophs to heterotrophs, which is associated with the predator vs. prey "evolutionary arms race." This intensified struggle to survive encouraged faster mobility (possible because of O_2 metabolism), shells and claws (possible because of increased mineral content of sea) and neural sophistication (nerve nets to ganglia and eventually brains). Together these environmental and biological factors led to the "Cambrian Explosion," a period of fantastic evolutionary change and diversity lasting over several million years and beginning approximately 543 million years ago. In that short period, all but one of the major phyla and body patterns evolved.*
>
> —*On-line text:* Evolutionary Biology: Earth and Beyond*, 2660.*

Now he was getting somewhere. Jay took the creased sketch paper from his pocket and compared the strange drawings to the text book illustrations. Sure enough, the paper matched almost exactly the ancient fossil illustrations from the screen. Jay looked at the simple drawings in awe. How, he wondered, could creatures from the Earth's distant past have surfaced on an alien planet millions of years in the future? Although the planet had originally seemed to fit Pre-Cambrian Earth's calm description, there had been no major glacial events, no undersea volcanos or millenniums of oxygen-building bacteria. Could the colonists have inadvertently tipped a planet on the edge of an alien "Cambrian Explosion"?

Jay was getting uneasy. Let's assume, he thought, that the early colonists found conditions here similar to Earth's Pre-Cambrian, and that this simple planet was indeed slowly changing as Earth had been in the Pre-Cambrian. Further suppose that the colonists speeded up the process exponentially by dumping in oxygen and sediments. Then assume that the environment and organisms were able to evolve at an incredible speed—after all, "break neck evolution" was a recognized phenomenon on some alien planets. If the path of evolution on P-L5 had followed that on Earth, seas would have turned murky with sediment, and "Ediacaran fauna" might have given way to a host of shelled, swimming and burrowing creatures clogging the water pipes. Predators like Earth's three-foot-long *Anomalocaris* would have scared tourists and residents alike. Perhaps a frightened populace had decided to get out before it was too late, before the new creatures emerged from the sea to take their first steps on land as Earth's creatures had later done.

Tomorrow Jay and his colleagues would have to make a decision that would affect hundreds of people and an entire planet: whether to re-colonize P-L5 or leave it for good. What he needed was information—enough to convince an entire team of scientists, investors, judges and colonists of just what they were getting into.

Discussion Questions

1. How were the Ediacaran organisms adapted for their environment?
2. What major changes were occurring in the environment around the time of the "Cambrian Explosion"?
3. Which of these changes were affected by the organisms themselves; which were purely geological trends?
4. On P-L5, humans changed the environment in ways mimicking the forces on early Earth. Do you really think that "Earth-like" animals would have evolved again? Why or why not?
5. Assuming that this planet was undergoing an "Alien Explosion" similar to the "Cambrian Explosion" on Earth, what would you expect to evolve next?
6. Is the planet safe for colonization? Why or why not?

Tomorrow you will be expected to present a full report on the environmental and biological conditions on P-L5 as well as a decision on re-colonization. Each member of your group will represent one interest in this decision such as scientist, colonist, investor, etc., and will have to support your group's decision before a preliminary court. Be prepared to justify your decision with theories on evolution as well as actual examples from Earth. In addition to other materials, you will need to know:

1. What were the initial conditions on P-L5?
2. How were those conditions similar to "Vendian" Earth? How were they different?
3. How did the colonists change P-L5? Why did they change it and what effects did those changes have on the planet and native organisms?
4. What led to Earth's "Cambrian Explosion"?
5. Could the "Alien Explosion" on P-L5 be slowed or controlled? Could the planet be made safe for re-colonization?

Role Assignments

- High Court Judges
- Investor for Re-Colonization
- Investor Against Re-Colonization
- Biologist for Re-Colonization
- Biologist Against Re-Colonization
- Geologist for Re-Colonization
- Geologist Against Re-Colonization
- Chemist for Re-Colonization
- Chemist Against Re-Colonization
- Civilian for Re-Colonization
- Civilian Against Re-Colonization
- Intern for Re-Colonization
- Intern Against Re-Colonization

Thank you and good luck! Hundreds of people are awaiting this mission's final decision.

High Court Judges

Official Memorandum

To: Esteemed Judges of the Starfleet High Tribunal on Re-Colonization
From: Supreme Court Justice Smith
Re: Re-Colonization of P-L5

I understand that you are going to be reviewing a re-colonization case for a planet in the Fifth Quadrant, P-L5. I would remind you that this is the first such "re-colonization" attempt in 30 years, and your decision carries great importance. I would also warn you that special interests are attempting to influence the case on both sides. It is your duty as judges to investigate the evolutionary matter thoroughly so as to be sure of the evidence and arguments presented in court. I would urge you to familiarize yourself with the various facts and theories of evolution and question both sides of the presenters freely. I have placed a large group of specialists on hand to advise you in your decision. Feel free to call on them to explain a fact or point out a discrepancy in the lower court's argument. I will be watching this case carefully. Good luck!

W. B. Smith,
Supreme Court Justice

Leads and Sources

Magazines and Articles

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Gee, H. 1995. The molecular explosion. *Nature* 373(6515): 558–559. <https://doi.org/10.1038/373558a0>

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Internet Sites

The Divisions of Precambrian Time: <http://www.ucmp.berkeley.edu/precambrian/precambrian.html>

Life of the Vendian: <http://www.ucmp.berkeley.edu/vendian/vendianlife.html>

Learning About the Vendian Animals: <http://www.ucmp.berkeley.edu/vendian/critters.html>

Books

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Investor for Re-Colonization

To: Investor

From: K&P Securities Inc.

Re: Investments

I don't think I need to remind you of the importance of this decision. P-L5 once brought 2 billion dollars a year into our company finances and we cannot afford to miss this opportunity. Re-settlement must begin at once! The initial investment needed to rebuild this colony is incidental when compared to the trillions of dollars it would take to locate, study, and prepare a new planet. All the infrastructure, buildings, roads and landscaping are intact. As for the "Alien Problem," we humans have been dealing with far more complex and dangerous life forms for millennia on earth—why should we jump at the sight of a few trilobites? So the people can't go to the beach—we'll build a "Cambrian Park" that will knock their socks off! And if the things evolve again, well, we'll just put in a couple of strategic fences. I have compiled a short list of resources you might find useful. I don't care what you argue so long as you convince those judges to re-colonize.

I'll be waiting,

J.D Kaper, CEO K&P Securities

Investor Against Re-Colonization

To: Investor

From: L&R Financing

Re: P-L5

I don't need to remind you how much the judges' decision tomorrow will affect our future—and yours. L&R Financing financed the original P-L5 colonization in cooperation with our partners K&P Securities Inc. However, since the abandonment of the colony almost 100 years ago, we have maintained a discreet and highly lucrative Californium mine on the far side of south island. Should re-colonization begin, we would not only have to abandon and cover-up our operations, but face possible environmental charges in the future. The press would kill us if they knew we've been leaking radioactive waste into P-L5's seas for over a hundred years. But, if re-colonization is denied, everyone goes home and we continue to conduct our business as usual. Your job is to convince the judges to veto re-colonization. I have spoken to several specialists in evolution issues and they all agree you could make a good case. You might try to argue that the planet was unsafe and dangerous (incidentally, a really well-timed *Anomalocaris* washing up on shore can do wonders with an audience!). Evolution here is too far advanced to be controlled. According to Gould chance plays such an important role in evolution that using Earth as a "future forecast" is foolish. I don't really care what you argue as long as you win this case. P-L5 must not be colonized! I've had my secretary type up a list of resources that might help you tomorrow. Remember, we're counting on you!

Larry Czetsky III

Managing Director, L&R Financing

Biologist for Re-Colonization

Like the other crew members, you explored P-L5 carefully before coming to your decision. This planet was ideal for colonization. All the expensive O_2 priming, landscaping and infrastructure were done—people could move right in! As for the "critter problem," a couple of primitive snails and crabs didn't scare you. Besides, if your calculations are correct, it would take hundreds and hundreds of years before these "sea slugs" ever made it to land. Imagine the research possibilities! Here was evolution first hand! A glimpse into Earth's primitive past. The Science Facility was already fully equipped and capable of supporting a research team—led by you, of course. Maybe it would be a good thing if colonists weren't brought in just yet; it would give you time to study the planet and do some ground-breaking research. The best plan would probably be to support re-colonization and try to win a research grant to study the planet. If you play your cards right, you might just win the chance of the century.

Biologist Against Re-Colonization

To: Alex Kelly, Biologist

From: Scientists Against Space (SAS)

Re: P-L5

We are at a profound crossroads in our history as a species. With the current push to move populations off Earth and into surrounding planets, our galaxy has been thrown off and polluted as never before. Not only is colonization a risk to us, but to the planets and ecosystems we invade. P-L5 is a prime example of this crisis. Against the advice of our scientists, the planet was "adjusted," polluted and colonized. Oxygen levels were rapidly increased, the very chemical concentrations of its once beautiful seas were changed and foreign organisms were introduced. Is it any wonder that the seas turned murky and the native species frightening? We have already started this once harmless planet down an uncertain path, with new species and phylum that might one day threaten us. To re-colonize this planet would only put hundreds of people in danger and destroy what is left of this fragile ecosystem. As fellow scientists we urge you to convince the judges to ban re-colonization of P-L5.

Thank You!

Kim Menicken, Columbia Ph.D., Extraterrestrial Biology

Jim McCay, Boston U. Ph.D., Biotics

Nada Rachim, SUNY Buffalo. Ph.D., AstroPaleontology

Lu Wang, Lunar South Ph.D., Physics

Sam Goldwin, Harvard Ph.D., Marine Biology

Shifra Kayle, Oxford Ph.D., Dynamics

J.K Nafemaya, NYU Ph.D., Chemical Philosophy

P.M Cay, U.Mass Ph.D., Geobiology

Geologist for Re-Colonization

First of all, this whole alien evolution thing looks a bit fishy. In less than a hundred years alien organisms are able to do what it took Earth's creatures millions of years to do? And, speaking as a geologist, the right conditions just weren't there. No undersea volcanoes or plate tectonics, no glacier activity or limestone deposits on the sea floor. Even if a few organisms had indeed adapted to the new "Earth-like" conditions, it was statistically impossible that those creatures should simply repeat step-by-step the same changes and shifts that had taken place millions of years ago on Earth. Whatever was going on, somebody had an interest in keeping P-L5 uninhabited, and it's up to you to beat them.

Geologist Against Re-Colonization

When the voyage to evaluate P-L5 had been announced, you hadn't been able to resist signing on. It had been a long-running family joke that Great-Grandpa Jim had depopulated an entire planet in his younger days by hanging a fish outside the mayor's bedroom window. With your background in crowd psychology you could understand how such a joke could send an aging boom town packing. By the time Grandpa Jim was born, P-L5 was a has-been planet. Years of murky water, "critter sightings" and poor advertising decisions had turned the once booming tourist trap into one big vacancy. Townsfolk had already started leaving for brighter, busier planets, selling their businesses and homes to a financing company. When Great-Grandpa hung one of those big funny-looking fish that used to wash up on shore, the townspeople decided they had had it.

This planet didn't sound too dangerous in Grandpa's stories, but to you it looked downright eerie. Something was obviously going on here and the sea water was turning brown with chemicals. Not only that, but this planet was definitely "hot," and the radioactivity might be speeding up evolution. Geological forces similar to Earth's might be awakening, and who knows what was crawling around down there. The sooner everybody left the better—and tomorrow you would tell them so.

Chemist for Re-Colonization

Why does everybody always seem to forget the chemistry of evolution? Shells and plates require complex processes to turn calcium carbonate from the sea into shells on the backs of animals. The "Oxygen Revolution" changed life on Earth, allowing higher metabolism (Krebs Cycle) and wiping out life forms to create open niches. Nitrogen and phosphate also contribute to evolution because they allow animals to diversify and grow. DNA changes can't be ignored either, nor can the switch to heterotrophic feeding that allowed animals to grow in volume instead of spreading out for yet more surface area. And we haven't even begun to talk about the way the organisms themselves affect their chemical environment and how that environment then affects the organisms. P-L5 seemed like a simple chemical equation—control the reactants in the environments and you control the organisms that are produced. To convince the judges to re-colonize you will have to explain the chemical theories of evolution and the "Cambrian Explosion" and how you would limit them. Good luck!

Chemist Against Re-Colonization

Why does everybody always seem to forget about the chemistry of evolution? Shells and plates require complex processes to turn calcium carbonate from the sea into shells on the backs of animals. The "Oxygen Revolution" changed life on Earth, allowing higher metabolism (Krebs Cycle) and wiping out life forms to create open niches. Nitrogen and phosphate also contribute to evolution because they allow animals to diversify and grow. DNA changes can't be ignored either, nor can the switch to heterotrophic feeding that allowed animals to grow in volume instead of spreading out for yet more surface area. And we haven't even begun to talk about the way the organisms themselves affect their chemical environment and how that environment then affects the organisms. Evolution is very much like a series of reinforcing cycles that once begun are too complicated and powerful to stop. Besides, trying to chemically regulate this planet would be like trying to put out a fire with lighter fluid—who knows what effects it would have on the ecosystem here. Instead of harmless trilobites we might end up with all kinds of mutant life forms completely alien to our understanding and far beyond our control. It was a mistake to "adjust" this planet once for humans and doing it a second time would only create more problems. P-L5 was better left alone!

Civilian for Re-Colonization

When you agreed to be an impartial civilian participant on this voyage, you were just hoping to get a cheap flight home. But once you saw this beautiful planet, you couldn't help but get involved. P-L5 was everything you had always dreamed of as a kid in the closed-in metropolises of Earth. Compared to Earth this place was the Garden of Eden. Fresh air, open space, plenty of land. Houses! Real houses, like in your Grandma's old photos—no dirty tenements and 70-story complexes. Some of the other crew members worried about "alien monsters" and things, but all it turned out to be was a couple of sea predators and simple trilobites. What were they compared to the viruses, animals and gangs that ravaged Earth? You have less than two days to learn enough about evolutionary biology to convince a panel of judges that P-L5 should be colonized. Luckily, you stole Jay's biology computer counsel and read the sources below.

Civilian Against Re-Colonization

Yes, you had heard all the praises of this strange planet, but there still seemed to be a tiny little detail everyone was glossing over—it takes a heck of a lot more than a little trilobite to send thousands of people packing. Walking through the ghostly city by the shore you came upon government files left unlocked, empty homes and vacant businesses. These people had left homes, factories, businesses behind—and despite all their reassurances the investigative team still didn't know exactly what had made those early colonists leave. You have until tomorrow to figure out what happened on this planet and convince the re-colonization committee that P-L5 is better left alone.

Intern for Re-Colonization

Well, this was turning out to be one boring summer job. When you signed on as an undergraduate intern with the resident Starfleet Biologist, you figured fame would soon follow. What followed was endless hours of thankless lab work, coffee serving and errands. If you are ever going to break free of this scientist's shadow, now is the time; but reading up on some widely known, scientific theory on the Vendian, Ediacaran, Cambrian and why they occurred is not going to get you far. What you need is obscurity. Some strange theory on evolution that will prove why Starfleet should re-colonize while distinguishing you from the rest of the scientists. A quick glance at *Nature* and *Scientific American* reassures you that there are plenty of interesting theories to choose from.

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