The Art of Writing Scientific Papers

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The Art of Writing Scientific Papers

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2. Identify your high concept
3. Write your introduction

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I. Starting the Process

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Being in the Body

- Sit comfortably, with your back straight, your head erect, your eyes closed, and your feet flat on the floor. Starting with your feet on the floor, move your awareness slowly up through your body, noticing and releasing any tension in your joints. (5 minutes)
- Diaphragmatic Breathing: Place one hand just above your belly and inhale, feeling the pressure of your belly on your hand. Then exhale, letting your mouth and jaw relax. (5 minutes)

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Generating an Outline: The Classic Scientific Paper Structure

I. Introduction
II. Materials/Methods
III. Results
IV. Discussion/Conclusion

As a first step, type/write in each of these categories at the top of an otherwise blank sheet of paper.

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Generating an Outline: A Creative Approach

As a 1-hour exercise, imagine:

What questions is your smart beer-drinking scientist friend (SBDSF) liable to ask you about your work, in conversation over drinks?

The outline generated from your 1 to 3-sentence answers to your SBDSF's questions ("The Painless Interview") will take the shape of the classic scientific paper.

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Starting the "Creative Outline"

Your SBDSF would likely want to know the following:

- What's the general question or problem being studied?
- Why is this question or problem important?
- How is this question/problem connected to other work in the field?
- What is the specific approach you're using to study the question/problem?
- What will you argue (What is the "high concept")?

(The beginnings of an Introduction section)

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Now You're on a Roll! Your SBDSF is getting interested.

- What materials/methods am I using, and how would I use them?
- How long would I do X (a certain experimental action or process)?
- How many times do I do X to obtain a result?
- How would I repeat this experiment (or go about constructing this model)?

(The beginnings of a Materials/Methods section)

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The Roll Continues!

- **What was the experiment or simulation performed?**
- **What were the critical conditions?**
- **What were the critical controls?**
- **How did the experiment or simulation turn out—give details! (This one might require a few more sentences.)**

(The beginnings of a Results section)

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Now You're Beyond a Roll

- **What do the results indicate?**
- **What is the significance of the results?**
- **How are they connected to other results from other scientists?**
- **How might the results be wrong?**
- **Do you have problems** (related to this project!)**?**
- **How would you handle them?**
- **Now what? What next?**

(The beginnings of a Discussion/Conclusion section)

YOUR 1-3 SENTENCE ANSWERS TO ALL THESE QUESTIONS WILL HELP ORGANIZE YOUR THOUGHTS AND GENERATE CONTENT, WHILE RETAINING A CONVERSATIONAL TONE.

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NOW LET'S FOCUS ON YOUR INTRODUCTION

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First Sentence

The First Sentence Must Be Short and Sweet.

Keep the first sentence of your paper concise. The first sentence should quickly orient your reader, clearly informing him or her in two or (at most) three lines, 25 words or less, what your general subject matter is. **And then it should end!**

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The High Concept

- **The "high concept" (a term borrowed from the film industry) is a one-sentence encapsulation of what your paper is about.**
- **It doesn't have to be a simple statement. It does have to be an understandable and readable statement—whether or not it is simple, it has to be clear!**
- **It is useful in organizing and unifying your writing.**
- **It makes the reader want to keep reading.**
- **It provides the "wow factor" that's so indispensible at cocktail parties.**

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The high concept should be part of the introduction because:

The earlier the reader gets a sense of the **whole**, the easier it is for the reader to assimilate the **parts**, as these parts accrue in the process of reading.

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Write an Introduction That Ends the Suspense

1. **Orientation**—(First sentence) Start with orienting the reader—What is the general subject that you're talking about (e.g., geothermal energy)? Remember, short and sweet!

2. **Statement of the Problem/Issue/Context**—1-X paragraphs (depending on length)—What question or problem confronts you? Provide a context for what you say in your paper. This part might typically include a description of the problem, or a literature review to convey the state of science in relation to the question/problem—for example, developing enhanced geothermal energy systems.

3. **Statement of what you're focusing on in your paper, how you'll proceed (agenda), and the High Concept**—one paragraph—In the beginning of the last introductory paragraph, present your agenda in the paper (what you will talk about and perhaps how you will talk about it) and state your paper's high concept. (What is your solution, or your contribution to existing knowledge?)

In your introduction, tell your whole story in a broad, simple way.

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A Sample Introduction

The resource base for geothermal energy is enormous, but exploitation of this renewable resource is currently limited to hydrothermal systems, within which naturally present fracture networks permit fluid circulation and allow geothermal heat to be produced by tapping these hot fluids through wellbores. Most geothermal resources occur in rock that lacks fracture permeability and fluid circulation. "Enhanced" or "engineered" geothermal systems (EGS) aim to extract geothermal energy from these resources.

Previous attempts to develop EGS have all employed water as a heat transmission fluid (Lippman et al., 2002). Water has many properties that make it a favorable medium for this purpose, but it also has serious drawbacks. Several recent studies have found that injecting water into hot rock fractures causes strong dissolution and precipitation effects that change fracture permeability and make it very difficult to operate an EGS reservoir in a stable manner (Xu and Pruess, 2004; Blair et al., 2006; Cummings, 2007). Moreover, water is a sparse and valuable commodity in many areas, including the western U.S., and inevitable water losses during fluid circulation can represent a severe economic liability (Kennedy, 2004; Zhou et al., 2005).

The present paper compares the thermophysical properties of CO_2 and water, and examines pressure and temperature conditions for the flow of CO_2 in wellbores. We compare the flow behavior of CO_2 with the flow behavior of water, to identify both the favorable and unfavorable characteristics of CO_2 as an EGS working fluid. Our findings show that an EGS system running on CO_2 has sufficiently attractive features to warrant further investigation.

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Instructions for Interactive Exercise: Introduction

- Groups have ten minutes to:
  - Read the sample introduction independently
  - Agree on a spokesperson
  - Evaluate/agree as a group whether the introduction met the standards described on page 15. If the introduction works, why?
    - First sentence short and to the point?
    - Problem/question/issues/context clearly described?
    - Agenda and high concept included & effectively stated?
- Spokespersons briefly summarize their group's conclusions.

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II. Writing the Thing

- **Write before you feel ready!**
- **Limit your editing at this stage. Write quickly**—don't get bogged down on any one issue. If you're having trouble with one section, go on to the next.
- **Write for your SBDSF**—keep it conversational.

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III. Editing for Your Reader: No One Gets It Right the First Time

It's Not about You: Your SBDSF Puts on an Editing Uniform

1. **Individual Sentences**
   (Controlling Complexity, Preserving Clarity)

2. **Sentences in Context**
   (Writing Paragraphs with Focus, Coherence, and Emphasis)

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Individual Sentences: Who's Doing What?

- The temperature was initially set to 4°C. (*simple sentence*)
- Attempting to achieve these conditions, the temperature was initially set to 4°C, while holding the methane gas pressure at 4.8 MPa. (*complex sentence, with a problem*)
- Attempting to achieve these conditions, **[our modeling group? modelers? scientists? investigators? the authors? we?]** initially set the temperature to 4°C, while holding the methane gas pressure at 4.8 MPa. (*complex sentence, fixed*).

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Individual Sentences: Who's Doing What, Continued

Remember to:

- Have an introductory modifier refer to the subject of the sentence (even if the subject has to be created or made visible)—*avoid dangling modifiers!*
- Prefer active voice.

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Sentences in Context (Paragraphs): Focus and the Topic Sentence

- Most paragraphs contain a *topic sentence* that comes at the beginning of the paragraph (first or second sentence).
- This topic sentence announces the central idea of the paragraph and limits what follows in the paragraph to that central idea.
- It imposes unity (focus) on the paragraph.
- It should be related to the high concept or to the topic of the previous paragraph. (Avoid monster paragraphs!)
- It should *tend* to be short.

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Sentences in Context (Paragraphs): Cohesion through Identity and Transition

- Sentences at the beginning of a paragraph *and* within a paragraph should contain signals of *identity* or *transition* that refer back to the previous sentence, so that the reader can easily see the kind of relationship that's implied between one statement and the next one.

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Signals of Identity and Transition

Signals or terms of *identity* assert that something already treated is still under discussion. These terms are usually pronouns (*he, she, it*), repeated words and phrases, or demonstrative adjectives (*this, these, that, those*) that are understood in the light of the previous sentence.

Signals or terms of *transition* indicate *how* a statement will build on the previous one. For example:

Time or Place: *later, earlier, then, here, there, at the same time, above, below*
Consequence: *therefore, thus, as a result, consequently*
Likeness: *likewise, similarly*
Contrast/reversal: *but, however, nevertheless, on the other hand, yet*
Continuation/Amplification: *again, in addition, furthermore, moreover, also*
Example: *for instance, for example*
Sequence: *first, second, third…, finally*
Recapitulation: *in conclusion, to summarize, in summary*

Such signals needn't appear in every sentence, but they become useful whenever the relationship between two sentences wouldn't be immediately clear without them—as is the case fairly often in science writing!

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Sentences in Context: Transitions and Emphasis

- In a complex sentence, what comes last is most emphatic.
- Your reader expects the material *at the beginning of a sentence* to provide a connection backwards to already established material. They expect the material *at the end of a sentence* to be new and informative.
- So, rather than rushing to present new information at the beginning of a sentence, begin with *connective tissue*—a signal of identity or transition, or with terms repeated from the previous sentence—to provide a bridge between the old and the new information to come later in the sentence.
- Thus, the information at the beginning of a sentence should provide a launching pad for the new and important material to be presented toward the end of the sentence. That new material is *emphasized* by the structure of the sentence—it's the punch line!

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A Sample Main Body Paragraph

Similarly, when we look at flow rates, the potential advantages of a system using CO_2 rather than water become clearer. For high temperatures, flow rates for such a system are found to be ~50% larger than for water, a very substantial acceleration of energy recovery. CO_2 flow rates are in fact larger than for water by a factor of ~3.7 initially, and decrease less over time than water flow rates. For low temperatures, the viscosity of water increases much more than that of CO_2, giving CO_2 an additional advantage for flow in the vicinity of the injection well. From this analysis, we can conclude that much of the advantage of CO_2 is due to enhanced mobility at the lower temperatures prevailing near the injection well.

HC: "...an EGS system running on CO_2 has sufficiently attractive features to warrant further investigation"

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Instructions for Interactive Exercise: Main Body Paragraph

- Read the paragraph (3 minutes).
- Find a partner.
- Discuss whether the paragraph includes an effective topic sentence and stays on track (i.e., focused).
- Identify the terms of coherence (identity and transition) within the paragraph.
- Discuss whether the paragraph appears to have effective emphasis (i.e., do we seem to learn something new towards the end of sentences?).

Report back to Dan!

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Your Conclusion

- Analysis of your results or findings—Summarize the important results/findings and interpret them. This could start with a paragraph in which your topic sentence confirms your high concept, then the rest of the paragraph goes systematically through the key results and explains how they support your high concept.
- Significance of your results/findings—what does it all mean?
- Similar to your introduction, where you orient your reader (telling your reader what you'll be talking about), you want in your conclusion to *reorient* your reader, indicating how things have changed (or could change) in light of your results. Or you can remind the reader of what you didn't talk about, what was outside the scope of your discussion, or how some results suggest other possibilities, indicating the need for further research.

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CO_2 Paper Conclusion

The specific findings of our modeling studies show that EGS driven by CO_2 holds considerable promise. These findings can be summarized as follows:

- Due to its much larger expansivity and compressibility as compared to water, supercritical CO_2 will generate much stronger buoyancy forces between injection and production wells. This will reduce power consumption for the fluid circulation system and would allow adequate fluid circulation without external pumping.
- CO_2 will generate on the order of four times larger mass flows and larger heat extraction rates compared to water.
- Whereas the loss of water in a "conventional" (water-driven) EGS operation would be disadvantageous and costly, fluid loss in an EGS system running with CO_2 would offer the possibility of geologically storing this greenhouse gas.

[What follows for several pages is an elaboration of these points, explaining their significance.]

As we mentioned earlier, the heat-extraction and wellbore-dynamics studies pertain to what may be called "fully developed" EGS reservoirs, operating with either CO_2 or water as heat transmission fluid. We did not address the very important question of how such a reservoir would actually be created, focusing instead on the comparative heat-extraction efficiencies of fully developed water-based and CO_2-based EGS. For the practical feasibility and success of EGS-CO_2 development, the process of displacing water and replacing it with injected CO_2 will obviously be a crucial step to be explored in future studies.

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Instructions for Interactive Exercise: Conclusion

- Read the conclusion (3 minutes).
- Discuss with Dan whether the conclusion succeeds. If the conclusion is lacking, identify what the issues are.
    - Does the conclusion include an analysis of the important results?
    - Does it indicate the significance of its results, reorienting the reader with respect to larger scientific issues?
    - Does it suggest its own limitations and possibilities for further research?
    - Do the conclusions support the high concept?

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IV. Last Concerns—Abstract

The Abstract: Worth Your Tender Loving Care

- In terms of market reached, the abstract is the most important part of the paper—for every *one* person who reads your entire paper, from *10 to 500* will read the abstract.
- An abstract is an abbreviated representation of the paper *containing in itself the essential information* of that paper—it can stand alone, independent from the paper. It should state the purpose, results, and conclusions presented in the document, if possible with special emphasis on results and conclusions. Not quite a *summary*, in that a summary is typically a restatement *within a document* (in its conclusion) of its most important results and conclusions.
- A golden opportunity to break out your high concept or an encapsulized version of it, either at the beginning or (especially) the very end of it.

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CO_2 Paper Abstract

- Responding to the need to reduce atmospheric emissions of carbon dioxide, Brown (2000) proposed a novel enhanced geothermal system (EGS) concept that would use carbon dioxide (CO_2) instead of water as heat transmission fluid, and would achieve geologic sequestration of CO_2 as an ancillary benefit. Following up on Brown's suggestion, we have evaluated certain thermophysical properties and performed numerical simulations to explore the fluid dynamics and heat-transfer issues in an engineered geothermal reservoir that would be operated with CO_2. From our evaluations, we find that CO_2 offers certain advantages, especially with respect to wellbore hydraulics, in that its larger compressibility and expansivity compared to water would increase buoyancy forces and reduce the parasitic power consumption of the fluid circulation system. Given these findings, it seems clear that while major uncertainties remain with regard to chemical interactions between fluids and rocks, the thermal and hydraulic aspects of a CO_2-EGS system warrant further investigation.

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Takeaways

- Invent an SBDSF to ask you questions related to your paper.
- Keep first sentence short and sweet.
- Generate a high concept (and don't leave your introduction without one).
- Within every sentence, make sure the reader knows who is doing what.
- Provide sufficient connective tissue (transitions) between paragraphs and sentences.
- Write and edit with your SBDSF in mind—show *empathy*.

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V. Quick Editing Checks

Prefer Active over Passive Voice.

Look for and consider removing as many "to be" word forms (is/are, was/were) as possible within a sentence.

Passive Voice
The warning was displayed by the browser.
Barometric pressure was measured.
Mistakes were made.

Active Voice
The browser displayed the warning.
The team measured barometric pressure.
We made mistakes.

VERBS IN THE ACTIVE VOICE ARE STRONG, DIRECT, FORCEFUL, AND ECONOMICAL.

AND THEY ARE NATURAL TO YOUR CONVERSATIONAL VOICE.

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Prefer Active over Passive Voice (continued): Scrutinize Nominalizations

As much as possible, use verbs only for expressing action.

The dean made a decision to conduct a review of the matter.
The dean decided to review the matter.

There was a modification of the program by the director.
The director modified the program.

"Decision" and "modification" are examples of nominalizations, nouns made from verbs.

When editing, you should note your nominalizations and look to see if you can turn them back into verbs that express key action within a sentence.

This will add clarity and grace to your writing.

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Using "Which" or "That" (commas or no commas)

Grammatically,

that introduces a restrictive clause (providing identifying information about its antecedent). Place no comma before *that* or at the end of the clause it introduces;

which introduces a nonrestrictive clause (providing information *but not identifying information* about its antecedent). Place a comma before ***which*** and at the end of the clause it introduces.

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More That/Which

The rats that were fed a high-calorie diet were all dead by the month's end.

The rats, which were fed a high-calorie diet, were all dead by the end of the month.

Mice of the DBA strain that metabolize acetaldehyde slowly drink significantly less ethanol than other mice.

Mice of the DBA strain, which metabolize acetaldehyde slowly, drink significantly less ethanol than other mice.

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Serial Comma (Commas Separating Elements of a Series)

"He rose up from his chair, took a key out of his pocket, opened a locked cupboard, and brought forth a sack, a crowbar of convenient size and shape, a rope, a chain and other fishing implements." (from Charles Dickens, *A Tale of Two Cities*)"

Sentence structure: He a, b, c, and d 1, 2, 3, 4, 5(?)

The returning knight had countless tales to tell of adventure, conquest of hideous monsters and helpless damsels in distress.

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Articles (*the, a, an*)

The most basic of modifiers, articles clarify a reader's relationship to what they modify.

Articles are divided into *definite* (*the*) and *indefinite* (*a, an*); those three words compose the entire list.

The definite article (*the*) precedes the word for a specific item, whether singular or plural: the report, the atrocities, the stupidities

Often a definite article precedes an adjective, as in "The bigger they are, the harder they fall."

The indefinite article (a, an) precedes a general category, always singular, or a singular item not previously identified: A report is due. An idea of mine.

A is used before consonant sounds, *an* before vowel sounds. When an initial *h* is distinctly pronounced, as in "historical," use *a*, as in "a historical inquiry"; when the h is not distinctly pronounced, use *an*: "It is an honor to meet you."

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Semicolon

Use a semicolon to separate two independent clauses that you want the reader to see as closely connected.

The first of the hikers began to arrive not long thereafter; a light breakfast of coffee and freshly baked rolls was laid out for them in the small dining room."

TO SEPARATE ELEMENTS IN A SERIES THAT ARE ALREADY DIVIDED BY COMMAS

Conferences were held in Arlington, Texas, on May 1, 1989; in Golden, Colorado, on April 14, 1990; and in San Jose, California, on July 25, 1991.

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Colon

- Use a colon to introduce a list, or to introduce the answer to an implied question raised in the first part of the sentence (i.e., before the colon)
  - **We will discuss three editing problems today: misplaced modifiers, unclear antecedents, and redundancy.**
  - **One idea emerges, above all others: almost anything is possible.**
- Note that ***you don't introduce a list/series with a semicolon***! Semicolons can divide elements in the list if the elements are lengthy or have commas within them, but they can't introduce a list or series. Colons do that!

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Hyphens

The main use of hyphens is in compound modifiers occurring before the word they modify. But if the compound modifier occurs after the word (thus losing its role as a modifier), omit the hyphen:

mass-balance equations, *but* equations pertaining to mass balance

Many compound words (originally separate words) are now spelled as one word (no hyphen) in common usage.

henhouse, typesetting, makeup, notebook, byproduct

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Hyphens, continued

Some prefixes require following hyphens, but most (the most common ones) don't—

self-sufficient, quasi-realistic, *but* semisweet, nonqualified, underinflated, overexcited, interstate, intramural, postoperative

Sometimes hyphens are helpful (and thus allowable) when they clarify a word that otherwise might not be:

pre-test, post-test; pre-emptive, post-trauma

There's a gray area in using hyphenation, and there are plenty of cases that are "up for grabs." The writer needs in those cases to choose what would be the clearest form (in his/her judgment) and be consistent with it throughout the document.

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"The Dash Between Numbers"

Whenever you're indicating a number range, you want to use the *en dash* (–), which in width size is between the hyphen (-) and the dash (—). En dashes can often be found in reference lists, indicating the page-number range of a paper within a journal.

Wood, W., 1973, A technique using porous cups for water sampling at any depth in the unsaturated zone. *Water Resour. Res., R 9* (2), 486–488.

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Dashes

Known as *em dashes* in typesetting to distinguish them from the aforementioned *en dashes*, dashes can be used in much the same way as colons, to introduce and emphasize what comes later in a sentence. You can also use dashes to indicate a summing up of what you've said in the first part of a sentence, to indicate that you're moving on to the last part of the sentence.

We will discuss three editing problems today—misplaced modifiers, unclear antecedents, and redundancy.

Misplaced modifiers, unclear antecedents, redundancy—whatever your problem, call Dr. Phil (not Dr. Dan).

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Dashes, continued

Much as with parentheses, you can resume a sentence that the first dash interrupted, after a second dash. Thus, dashes are often an effective way of "shortening" a sentence (as are parenthesis), helping the reader get through a long, fully packed sentence with other punctuation.

Note that with respect to the reader, the psychological impact of the information enclosed in dashes is somewhat different from information similarly enclosed in parentheses. Whereas parentheses subordinate or "diminish" the information they contain, making it seem more tangential, information enclosed in dashes tends to stand out, drawing attention to itself.

No direct evidence exists—either from field observations or numerical simulation—that an eruptive release from a subsurface storage reservoir can be powered solely by the mechanical energy stored in an accumulation of compressed gas, without substantial contributions from thermal energy.

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