

Field science operations and the Mars laboratory



Conceptual visualization — field science links sampling context, contamination control, laboratory measurement, chain of custody and reproducible interpretation.

Turn observations, samples and local analysis into traceable science despite limited time, contamination risk and Earth-Mars delay. Destructive analysis is therefore scheduled only after context, documentation and non-destructive observations have protected the sample's future scientific value.

Before starting — Prerequisites: modules 00 to 40 recommended as relevant. Every important symbol is defined at first use.

Mastery objectives

- turn a field question into a testable hypothesis, sampling plan and evidence chain
- preserve sample identity, blanks, calibration state and custody from collection to interpretation
- separate observation, contamination, measurement error and inference when results conflict
- decide when evidence is strong enough to change a scientific or operational conclusion

1. Field science begins with a hypothesis

A field excursion should not be a collection of interesting objects. Before departure the team states questions: which layer is older, what environment deposited this unit, which orbital anomaly needs confirmation? Stations and samples are then selected to discriminate between hypotheses.

2. Structured observation before sampling

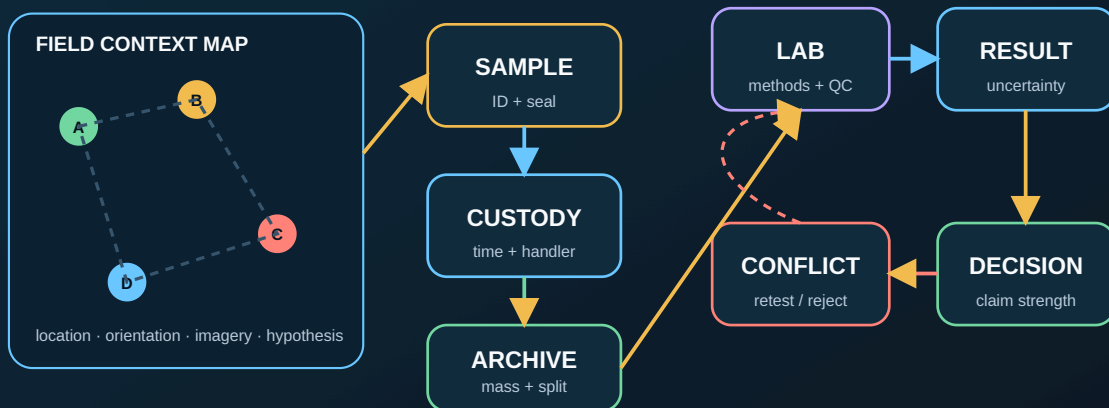
Overview photography, panorama, scale, orientation, texture description and relationships between units should precede collection. This sequence preserves sample context and allows a distant science team to understand what the crew actually saw.

3. Sample selection: diversity, representativeness and rarity

A mission balances typical material with unusual targets. Ten nearly identical fragments may be less useful than a smaller collection spanning several geological units. The collection plan therefore states the question associated with each sample.

Field-science evidence chain

A scientific claim is only as strong as field context, custody, laboratory quality control and uncertainty



A field result is credible only when the question, sampling plan, measurement and interpretation remain traceable. Pedagogical synthesis by Delta-Sierra from the primary sources cited in this course; schematic, not to scale.

4. Local laboratory: order destructive analyses carefully

Some analyses consume or alter material. Non-destructive measurements, imaging, mass and spectroscopy can precede crushing, heating or wet chemistry. Analysis order preserves the ability to revisit a sample with another instrument.

5. Chain of custody and contamination

Every transfer retains identifier, container, operator, time and environment. Blanks and witnesses distinguish Martian material from contamination introduced by tools, habitat or reagents. For a possible biosignature, this discipline is as important as instrument sensitivity.

6. Earth-Mars delay: local science autonomy

Earth specialists can recommend new priorities but cannot direct every action in real time.

Crew members need enough field training to recognize an unexpected observation, record why they changed the plan and preserve the information needed for later review.

7. Campaign planning: turn a scientific question into operations

A useful science traverse begins before departure. The research question must be translated into required observations, sample types, location precision, instruments, station order and criteria for changing the plan. Without that translation a traverse can collect many rocks without answering the original question. Planning must also include energy, local time, weather, mobility reserve, fatigue, airlock capacity and sample mass. Priorities are ranked so that an interrupted excursion still returns a minimum useful scientific result.

8. Laboratory workflow: separate preparation, measurement and preservation

A Mars laboratory should prevent one analysis from accidentally destroying the value of remaining material. Mechanical preparation, chemistry, microscopy and biology have different contamination risks. Workflow defines which tools touch which samples, how they are cleaned, which blanks accompany a batch and what fraction remains untreated. Metrology matters as much as the instrument: without calibration, drift checks and maintenance history, a number can look precise while being wrong. Data should preserve configuration, software version, measurement conditions and uncertainty.

9. Science autonomy: make local decisions without cutting off Earth

Earth-Mars delay prevents detailed permission for every sample. The crew therefore needs rules allowing a traverse to change when an unexpected outcrop appears while preserving programme objectives. Autonomy does not mean unrestricted improvisation; it rests on prepared hypotheses, value criteria and documented departures from plan. Context data,

preliminary analyses and sample inventories are then transmitted to Earth, where specialists can propose priorities for later sols. Science becomes a loop between distant planning and local decision-making.

10. Worked example: science EVA time budget

A 6 h EVA reserves 1.2 h for outbound and return travel, 0.8 h for airlock and safety operations and 0.6 h as margin. Science time = $6 - 1.2 - 0.8 - 0.6 = 3.4$ h. With five stations, average maximum time is 40.8 min/station including local movement. Adding two stations without changing EVA duration reduces the average to 29.1 min and may reduce observation quality.

Calculated case study: how many field stations actually fit into an EVA?

TEACHING ASSUMPTION — An EVA lasts 6 h, or 360 min. Round-trip travel uses 60 min, the safety margin uses 45 min and each complete science station requires 25 min: 15 min for context and 10 min for sampling.

Let T be total duration in minutes; T_{travel} round-trip travel in minutes; T_{margin} the safety margin in minutes; t_s station time in minutes; and N the integer number of feasible stations, dimensionless.

$T_{\text{science}} = T - T_{\text{travel}} - T_{\text{margin}} = 360 - 60 - 45 = 255$ min. $N = \text{integer part of } 255 \div 25 = 10$ stations, leaving $255 - 10 \times 25 = 5$ min.

The calculation shows why a six-hour EVA does not mean six hours of science. Travel and margin must be removed before promising a sample count; the values are teaching assumptions, not operational standards.

11. Exercise

Build an excursion around four science hypotheses, six possible stations and only four that can be completed. Justify the selected stations and the sample associated with each one.

12. Reasoned solution

A strong campaign selects a small number of stations directly linked to the hypothesis, reserves time and energy for an unexpected target, and states which samples remain highest priority if the excursion is shortened. Every collected item retains context, identifier, position and handling chain; a rock without context can lose most of its scientific value.

13. Validation mini-project

Produce a complete science-operations plan: objectives, traverse map, observation sheet, sample nomenclature, chain of custody, analysis order, autonomous replanning rules and the data package sent to Earth.

Field science on Mars is an operational chain from question to evidence, not a collection of interesting rocks

A scientific campaign begins before anyone walks outside. The team must define a question that observations can actually discriminate, decide what measurements or samples would change the interpretation, and identify the controls needed to distinguish a real signal from contamination or instrument drift. Without that structure, a crew can return with beautiful specimens and terabytes of data that do not answer the original question.

Field work is expensive because every station consumes EVA time, mobility range, suit consumables, communications attention, sample capacity and later laboratory effort. A good plan therefore separates must-have observations from desirable additions. The crew records context before disturbing the site, because stratigraphic position, texture, orientation and association can be impossible to reconstruct once a sample has been removed. Science quality depends on preserving relationships, not just objects.

The local laboratory is part of the campaign rather than a separate destination. Some analyses are non-destructive and can guide which samples deserve scarce destructive tests. Other procedures consume material, alter mineral phases or risk contamination. The team should

therefore sequence measurements from least destructive to most destructive where scientifically appropriate, while preserving archive material for later instruments or for possible return to Earth.

Calibration, blanks, standards, duplicates and metadata are what make measurements interpretable months or years later. A number without instrument state, method, location, time, operator and sample history may be impossible to compare with a later result. Mars-Earth delay reinforces this need because the local crew must often decide whether to repeat a measurement or modify a traverse before specialists on Earth can respond.

Planetary protection and crew contamination control add another boundary. Samples, tools, suits and laboratory spaces can move terrestrial organisms, dust and chemicals between environments. Procedures must distinguish scientific contamination, biological protection and ordinary occupational cleanliness. These goals overlap but are not identical; a method that protects crew health may still ruin a trace-organic measurement if it introduces the wrong cleaning chemical.

Twelve practices that turn a traverse into defensible science

1. Start with a testable question

A useful field question identifies competing interpretations and the observation that would make one interpretation more plausible than another. “Study this outcrop” is a destination, not a scientific question. “Does this layer contain textures and mineral associations consistent with repeated water-rock interaction?” gives the crew a reason to photograph specific contacts, compare units and collect paired samples.

Testable questions also protect mission time. When a new feature appears, the crew can ask whether it bears on the campaign hypothesis or deserves a documented opportunistic observation rather than derailing the traverse. Curiosity remains essential, but it is managed against the finite operational budget.

2. Record context before touching the target

Images, scale, orientation, surrounding units, bedding relationships, surface condition and the exact sampling position should be captured before tools disturb the scene. A specimen can retain chemistry while losing the field relationship that explained how it formed. Context is therefore part of the sample and deserves the same chain of custody.

A standard observation sequence reduces omission under time pressure. Wide scene, intermediate context and close detail can be linked to a common station identifier. Notes should distinguish direct observation from interpretation so later reviewers can reconsider the hypothesis without losing what the crew actually saw.

3. Design sampling for variation, not for the most attractive specimen

Scientific sampling should represent the range needed to answer the question: different layers, distances from a contact, altered and unaltered material, or multiple points across a gradient. Collecting only visually striking material can create selection bias. The plan therefore specifies why each sample exists and what comparison it enables.

Replicates can reveal natural heterogeneity or measurement scatter. They are not wasted mass when variability is central to the question. Conversely, collecting many near-identical samples without a comparison logic consumes storage and laboratory capacity without increasing information proportionally.

4. Keep calibration, blanks and controls conceptually separate

Calibration connects instrument response to a known reference. A blank checks whether the method or handling path introduces a signal when the target substance should be absent. A control provides a comparison condition that helps interpret change. These tools answer different quality questions and should not be treated as interchangeable administrative rituals.

Field plans identify where each control enters the chain. A clean tool blank can test sampling contamination; a procedural blank can follow containers and preparation steps; a reference standard can check instrument drift. When a result is surprising, these controls help determine whether the surprise belongs to Mars or to the measurement process.

5. Metadata is the memory of the experiment

Every sample and data product should link to location, time, operator, instrument, software or method version, environmental conditions and relevant configuration. The amount of metadata must be manageable enough that crews actually capture it. Automated acquisition can reduce burden, but operators still need a way to add observations and anomalies that sensors do not know.

Identifiers should remain stable through field, transport, laboratory subsampling and archive. Renaming files casually or copying labels by hand creates opportunities for silent mix-ups. A robust system makes provenance visible from the final analytical result back to the original station.

6. Chain of custody protects both identity and condition

Custody is not only a legal concept. In science it means knowing who handled a sample, which container it occupied, what temperatures or atmospheres it experienced, and whether the seal was broken. This record lets researchers decide whether a later anomaly could have been introduced during handling.

For fragile or volatile samples, condition can matter as much as identity. Storage rules may include temperature limits, shielding from light, vibration protection or controlled atmosphere. The scientific value of a sample is the combination of material and preserved history.

7. Sequence laboratory work from informative to irreversible

Visual inspection, imaging, mass measurement or non-destructive spectroscopy may guide whether a sample deserves cutting, heating, dissolving or other destructive preparation. The best sequence depends on the scientific objective, but the decision should be explicit because consumed material cannot be recovered.

Archive fractions provide insurance against future instruments and revised hypotheses. A crew under pressure to produce immediate results may be tempted to use every gram. Preserving a documented fraction can be scientifically more valuable than one additional current measurement, especially when resupply or return is impossible.

8. Quality control needs repetition at the right places

Repeating every measurement is inefficient, but never repeating measurements makes it hard to recognize drift or random error. The plan selects critical checkpoints for duplicates, standards or independent methods. Repetition is most valuable where a result drives a major interpretation or an irreversible decision.

Unexpected disagreement should trigger diagnosis, not averaging by habit. The team examines calibration, sample heterogeneity, preparation, environmental conditions and software processing. Averaging two incompatible numbers can hide the very clue that identifies the failure mode.

9. Field autonomy requires pre-agreed decision rules

Earth specialists may not be able to answer before the crew must move on. The campaign can therefore define local triggers: if a measurement exceeds a threshold, take a second sample; if an instrument fails calibration twice, switch to the backup method; if a site consumes more than the allocated time, preserve a minimum observation set and continue.

These rules do not remove scientific judgment. They protect it by giving the crew authority within a shared framework. Later Earth review can still redirect future sorties, but the current EVA is not paralyzed by communication delay.

10. Science competes with maintenance and safety for the same people

A settlement does not have a separate unlimited science workforce. The geologist may also be an EVA specialist, mechanic or medical responder. Campaign planning therefore includes crew-hours, recovery time and the probability that urgent maintenance cancels a sortie. A scientifically elegant schedule that assumes no operational interruptions is fragile.

Priorities should preserve rare opportunities without endangering settlement reliability. A transient atmospheric event or seasonally accessible site may deserve protection in the schedule, while routine sampling can move. Explicit priority makes trade-offs defensible when operations become crowded.

11. Data volume is not the same as information value

High-resolution instruments can produce more data than can be reviewed locally or transmitted promptly. The team should preserve raw data where practical while creating summaries, quality flags and prioritized products for decision-making. Compression or down-selection must not erase the context needed to reinterpret a surprising result later.

Data handling also includes checksums, redundant storage and version control for derived products. A scientific archive must survive equipment failures and software updates just as a life-support log does. The difference is that lost science data may be irreplaceable even when no immediate alarm sounds.

12. Interpretation must label uncertainty and alternatives

Field teams are vulnerable to confirmation bias because they see the campaign unfold and may become invested in an early hypothesis. Reports should separate observation, inference and speculation, and record plausible alternatives. A strong scientific result can remain valuable even when the favored interpretation later changes.

Uncertainty is not weakness. It tells later researchers which measurements are robust and where new evidence could change the conclusion. The objective is to produce a traceable argument whose assumptions can be tested, not a dramatic headline from every sortie.

Field-science calculation laboratory: EVA time and station capacity

Formula 1 — available scientific station time inside an EVA

$$t_{\text{science}} = t_{\text{EVA}} - t_{\text{travel}} - t_{\text{setup}} - t_{\text{reserve}}$$

Starting question

How much time remains for actual observation and sampling after mandatory travel, setup and contingency reserve?

Read aloud

Read: “science time equals total EVA time minus travel time, setup time and protected reserve.”

Symbols, pronunciation and meaning

t_{EVA} is total approved EVA duration; travel includes outbound and return movement; setup covers airlock-side or field

preparation included in the chosen boundary; reserve is time intentionally protected for uncertainty; t_{science} is usable station work time.

Units

All terms use the same time unit, such as minutes.

Origin and status of values

Times come from route planning, drills and mission rules. Reserve is an explicit planning choice and should not be silently consumed to make the science plan fit.

Why this operation

Subtraction removes activities that must occur even if no science is performed, exposing the time that can be allocated among stations.

Substitution and calculation

For a 360 min EVA with 100 min travel, 40 min setup/pack-down and 60 min protected reserve: $t_{\text{science}} = 360 - 100 - 40 - 60 = 160$ min.

Calculator entry

Enter $360 - 100 - 40 - 60$.

Mental estimate

Roughly half of six hours remains after about three hours of travel, setup and reserve, so 160 min is credible.

Independent check

Add $160 + 100 + 40 + 60 = 360$ min to recover the approved EVA duration.

Physical or operational interpretation

Only 160 min can be promised to station tasks. A plan containing four 50-minute stations is already impossible before any delay occurs.

Plain-English translation

In plain language: the six-hour EVA contains only two hours forty minutes of planned science in this example because safe movement and reserve consume the rest.

Variation / sensitivity

If travel grows by 30 min, science time falls to 130 min unless another term changes. If a nearer site saves 20 min travel, that entire saving can increase science or reserve.

Limit / assumption

The equation assumes the time categories do not overlap. Real EVAs may combine observation with travel or require

additional pauses, medical checks and unexpected troubleshooting.

What this does not prove

This subtraction only allocates scheduled time. It does not prove that the selected science tasks are worthwhile, that terrain permits the traverse, or that weather, suit performance and unexpected troubleshooting will preserve the planned categories.

Boundary case to test

If travel + setup + protected reserve exactly equals total EVA duration, science time must be zero. If those protected terms exceed the EVA duration, a negative answer means the plan is infeasible and must be redesigned rather than interpreted as usable science time.

Formula 2 — simple sampling allocation across stations

$$n_{\max} = \text{floor}(t_{\text{science}} / t_{\text{station}})$$

Starting question

How many complete stations fit when each station requires a minimum planned duration?

Read aloud

Read: “maximum station count equals the whole-number part of science time divided by time per station.”

Symbols, pronunciation and meaning

t_{science} is available scientific work time; t_{station} is the planned minimum per station; floor means keep only complete stations; $n_{\max}$ is count.

Units

Both times use the same unit; the result is a dimensionless count of stations.

Origin and status of values

Station duration comes from the required observation, documentation, sampling and packaging sequence, preferably measured in realistic drills.

Why this operation

Division asks how many equal station blocks fit. Taking the floor prevents claiming a partial station as if it were

complete.

Substitution and calculation

With 160 min available and 35 min per station: $160/35 = 4.57$, so floor gives 4 complete stations, leaving 20 min.

Calculator entry

Enter $160 \div 35$, then keep four complete stations.

Mental estimate

Four stations need 140 min; five would need 175 min, which exceeds the 160 min available.

Independent check

Check directly: $4 \times 35 = 140 \leq 160$, while $5 \times 35 = 175 > 160$.

Physical or operational interpretation

The leftover 20 min can remain reserve or support opportunistic observation, but it is not enough for a fifth station under the declared method.

Plain-English translation

The plan can confidently promise four full stations in this simplified schedule.

Variation / sensitivity

Reducing the station method to 30 min allows five stations with 10 min left; increasing travel and reducing science time to 130 min allows only three 35-minute stations.

Limit / assumption

Station durations are not always equal, and scientific priority may justify unequal allocation. A real traverse uses a task list rather than forcing every site into one duration.

What this does not prove

The station-count formula does not prove that stations have equal scientific value or equal task duration. It is a capacity check for a repeated minimum station procedure, not a method for prioritizing discoveries in the field.

Boundary case to test

If t_{science} is smaller than t_{station} , $\text{floor}(t_{\text{science}}/t_{\text{station}})$ must return zero complete stations. Exact multiples leave no schedule remainder, while $t_{\text{station}} = 0$ is physically meaningless and makes the division undefined; every station must carry a nonzero operational duration.

Campaign cases: protect evidence while operating under Mars constraints

A surprising organic signal appears in the first sample

The crew should preserve the excitement without immediately declaring discovery. They review blanks, standards, tool history, cleaning chemicals and sample handling, then repeat the measurement if enough material remains. A second sample from related context can test whether the signal is spatially coherent. The team records the instrument configuration and preserves an archive fraction before performing more destructive tests.

If controls are clean and independent evidence supports the observation, the finding becomes stronger. If a blank shows the same signal, the campaign has learned about contamination rather than Mars chemistry. Either outcome is scientifically useful when provenance is complete. The dangerous outcome is a dramatic number with missing controls that no one can later interpret.

A rover wheel issue cuts the traverse range in half

The science lead re-ranks stations by information value and by the questions they discriminate. A distant attractive site may be dropped in favor of nearby paired observations that preserve the core hypothesis test. The crew should not simply visit the first half of the original route, because that may destroy the sampling design.

Route change is documented so later analysts know why some planned samples do not exist. If the missing station creates a major comparison gap, a future EVA can target it specifically. Operational adaptation is part of scientific method when the change is transparent.

A sample label is unreadable after return to the habitat

Identity should be reconstructed only from independent records such as container sequence, timestamped imagery, tool logs and digital station identifiers. If more than one origin remains plausible, the sample is marked uncertain rather than assigned the most convenient identity. Scientific databases should preserve that uncertainty.

The incident then drives a procedural correction: redundant human-readable and machine-readable identifiers, protected labels, verbal confirmation or digital scans before containers leave the field. A chain-of-custody failure is a systems problem, not just an operator mistake.

A laboratory instrument fails calibration during a critical campaign

Repeating the same calibration indefinitely can consume standards and time without improving confidence. The procedure defines how many attempts are reasonable, which diagnostic checks follow and whether a backup or alternate measurement can answer the key question. Samples may be preserved rather than forced through a questionable instrument.

Earth specialists receive the calibration history and raw diagnostics, but local operators retain authority to protect sample integrity. The right decision may be to delay analysis until repair rather than produce numbers whose traceability is already compromised.

Maintenance cancels two planned science days

The campaign is replanned around scientific dependencies. Samples requiring a particular seasonal condition may outrank routine monitoring, while laboratory work on already collected material can fill time when EVA personnel are unavailable. The science team also checks whether maintenance activities themselves generate dust, vibration or chemical contamination that affect experiments.

This avoids treating science and settlement operations as rival departments. The same planning board can expose shared resources and opportunities. Reliable habitation is a prerequisite for sustained science, while good science can improve site knowledge and resource decisions.

A sample may contain a volatile component

Handling should minimize unplanned heating, venting and time at conditions that alter the target. The team chooses a compatible sealed container and records temperature and transfer history. Laboratory sequence prioritizes measurements that can characterize the volatile fraction before destructive preparation changes it.

The key principle is preservation of scientific state. A perfectly labeled sample can still lose its value if the material evolves during storage. Chain of custody therefore includes environmental history, not just possession.

Field-science practice with reasoned solutions

Exercise 1 — Turn a broad goal into a testable question

Rewrite “study the old river channel” as a question that guides observations and samples.

► Reveal the reasoned solution

Exercise 2 — Budget station time

An EVA is 420 min. Travel takes 130 min, setup/pack-down 50 min and protected reserve 70 min. How much science time remains?

► Reveal the reasoned solution

Exercise 3 — Choose samples across a gradient

You have six containers for a contact between altered and unaltered rock. How would you avoid selecting only the most visually dramatic pieces?

► Reveal the reasoned solution

Exercise 4 — Diagnose a contaminated blank

A procedural blank shows the same trace signal as several samples. What should happen before claiming the signal is Martian?

► Reveal the reasoned solution

Exercise 5 — Protect sample identity

A sample is split into three laboratory subsamples. What metadata relationship should be preserved?

► Reveal the reasoned solution

Exercise 6 — Decide whether to repeat a measurement

Two replicate measurements disagree strongly. Why is taking their average not the first response?

► Reveal the reasoned solution

Exercise 7 — Plan local autonomy

Earth cannot answer for twenty minutes, and the crew must decide whether to take an extra sample before leaving. What preplanned rule could help?

- Reveal the reasoned solution

Exercise 8 — Separate observation from interpretation

Write one observation and one interpretation for a layered rock face.

- Reveal the reasoned solution

Field campaign cases: evidence, contamination and autonomy

A field team discovers an unexpected stratigraphic contact late in the EVA

The crew first captures context imagery and a concise description before deciding whether to sample. The pre-agreed decision rule can permit one opportunistic sample if reserve time, container capacity and contamination controls remain above thresholds. If not, the location is marked precisely for a later sortie. This preserves the discovery without allowing excitement to consume return margin.

Back in the habitat, the contact is placed against the original hypothesis and traverse map. The next campaign can be redesigned deliberately rather than treating the opportunistic observation as an isolated curiosity.

A drill bit previously used on one sample touches another target

The contamination risk depends on the scientific question. For bulk mineralogy the carryover may be negligible after cleaning; for trace organics it may invalidate the measurement. The crew records the contact event and decides whether to collect a new sample with a clean tool, downgrade the sample to another analysis, or preserve it with a contamination flag.

Traceability protects value even after a mistake. Hiding the event would create a stronger-looking but less trustworthy dataset. Scientific operations reward accurate provenance over perfect appearance.

A sample container seal is found partly open after transport

Identity can remain secure while environmental integrity is uncertain. The sample is isolated, the condition documented, and analyses sensitive to atmosphere, moisture or volatile loss are flagged. Other properties may still be usable. The team should not discard all scientific value nor pretend the seal failure had no consequence.

The container lot and closure procedure are reviewed because one partial opening may indicate a mechanical or human-factor pattern. Corrective action can include tactile confirmation, secondary indicators or improved glove-compatible closure geometry.

Two instruments give different mineral identifications

The team examines what each instrument actually measures and the uncertainty of the algorithms rather than choosing the preferred answer. Sample heterogeneity, calibration, spectral overlap or preparation can explain disagreement. A third method or targeted subsample may discriminate the alternatives.

The report preserves both results and the reasoning used to reconcile them. Scientific confidence should grow from converging independent evidence, not from suppressing inconvenient measurements.

A dust storm cancels exterior work but the campaign clock continues

Laboratory priorities can shift toward processing existing samples, reviewing metadata, maintaining instruments and preparing future routes. The team identifies analyses whose results can improve the next field decision once EVA resumes. This turns weather delay into useful campaign work rather than simply compressing all remaining field stations into fewer days.

If seasonal access is being lost, the science lead may drop lower-value targets. The revised plan records what question can no longer be answered and what minimum dataset still supports a useful conclusion.

A promising sample is too large for the available archive container

The crew should not fracture it casually if spatial texture or internal relationships are important. They can document the intact specimen, choose a representative subsample with orientation information, or defer collection for a larger container. The trade depends on what information is preserved by geometry versus material chemistry.

This is a reminder that sample hardware constrains science. Container sizes, cutting tools and mass limits should be reviewed against expected target types before the campaign.

A weekly campaign is consuming more crew-hours than planned

The science team decomposes the overrun into EVA preparation, field tasks, laboratory handling, data processing and maintenance. Some steps may be automated or simplified without reducing quality; others are irreducible controls that should remain. Removing blanks or metadata to save time would create apparent productivity at the cost of scientific validity.

Priority can shift toward fewer well-documented stations. Information per crew-hour is a legitimate planning measure when habitability and maintenance compete for the same people.

Earth requests an additional measurement after the crew has already left the site

The team determines whether archived samples or recorded imagery can answer the request. If not, the request becomes a candidate for a future traverse and is weighed against other priorities. Communication delay means Earth cannot assume a field site remains instantly accessible.

This encourages specialists to design decision trees before an EVA: what result would trigger which follow-up measurement? Preplanned branches let the local crew act while the site is still in front of them.

A sample shows large internal heterogeneity

One analytical value may not represent the whole specimen. The team documents visible domains, takes controlled subsamples and treats variability as part of the scientific result. Averaging without recording structure can erase evidence of multiple formation processes.

Sampling strategy can then expand to the outcrop scale: is the heterogeneity unique to the specimen or systematic across the unit? Field and laboratory observations inform each other iteratively.

A software update changes the processing pipeline mid-campaign

Derived results before and after the update may not be directly comparable. Version control records which algorithm produced each product, and representative raw data can be reprocessed through both versions to quantify the change. The original raw measurements remain preserved

so interpretation does not depend permanently on one software state.

Operational science therefore treats code configuration as measurement metadata. A silent algorithm change can mimic a geological trend if provenance is weak.

A field note contains an interpretation later shown to be wrong

The original note should remain in the record with a later annotation rather than being rewritten as if the team always knew the correct explanation. Preserving the sequence of reasoning helps reviewers understand why samples were chosen and prevents hindsight from altering provenance.

Scientific archives distinguish observation from interpretation partly for this reason. A mistaken interpretation can be corrected; a lost original observation cannot be reconstructed.

A rare sample must be divided between immediate analysis and long-term archive

The allocation is based on which measurements are necessary to answer the current question and how much material future methods may need. Non-destructive characterization can guide where to cut, and subsample identifiers preserve orientation and parent relationship. The team explicitly records what fraction remains untouched.

This discipline protects against short-term pressure for complete analysis. On Mars, preserving material for a future instrument or Earth laboratory may be one of the highest-value scientific decisions the local crew makes.

Science campaign design dossier: traceability and laboratory continuity

Design dossier — design the campaign around discriminating evidence

A traverse should not maximize the number of stops; it should maximize the evidence that separates competing explanations. Before departure, the science team can create a matrix linking each station and sample to the hypothesis it tests. If two stations provide nearly identical evidence while another critical comparison is absent, the plan is unbalanced even if total sample count is high.

This matrix becomes valuable when operations force cuts. The crew can drop redundancy where it adds little while preserving the minimum set needed to discriminate the main alternatives. Scientific priority becomes explicit rather than based on whichever target appears most exciting in the moment.

Design dossier — preserve orientation and geometry when they carry information

Some samples are valuable not only for composition but for direction: bedding orientation, fracture fill, magnetic fabric or a contact between two units. Containers and labels should preserve the orientation marker or photographic relationship needed for later analysis. Breaking a sample into convenient pieces can erase the structure that made it scientifically important.

Field protocols therefore specify when orientation, top/bottom relationship or exact position must be recorded before removal. The extra seconds are justified when the information cannot be reconstructed after the specimen reaches the laboratory.

Design dossier — keep sample preparation zones logically separated

Cutting, crushing, sieving and chemical preparation can generate dust or residues that contaminate trace analyses. Laboratory layout should separate dirty preparation from sensitive measurement and clean storage. Tools can be dedicated by method or cleaned through validated procedures, and airflow or containment should prevent fine particles migrating between benches.

The laboratory chain is only as clean as its weakest transition. A pristine field sample can be compromised by a shared crusher or mislabeled vial. Facility design supports scientific integrity in the same way clean-room zoning supports hardware assembly.

Design dossier — use reference materials to track instrument health over months

Calibration is not only a pre-use action. Repeated measurements of stable reference materials can reveal gradual drift, detector aging or software changes across a long campaign. Plotting reference response over time allows the team to detect deterioration before it becomes obvious in unknown samples.

When an instrument is repaired or updated, the same reference set helps establish continuity between old and new configurations. Long-term science benefits from this metrological memory, especially when no Earth laboratory is immediately available to arbitrate

discrepancies.

Design dossier — plan destructive analysis as a decision tree

Instead of assigning every sample the same sequence, the laboratory can use non-destructive results to decide which destructive test is justified next. A sample that already answers the campaign question may be archived; another with an unusual phase may be split for additional work. The tree protects mass while directing effort toward the highest information gain.

The decision and consumed quantity are recorded. Future researchers can then understand why material was used and what remains. This is particularly important for rare samples that may never be collected again.

Design dossier — reconcile local autonomy with Earth expertise

The crew needs enough scientific authority to act during communication delay without severing collaboration with specialists on Earth. Shared decision rules, campaign objectives and preplanned branches provide that balance. Earth can define what evidence matters; the local team decides how to obtain it safely under actual conditions.

After each sol, compressed summaries and raw data priorities can be transmitted for deeper review. The next cycle incorporates Earth feedback. Autonomy becomes a time-scale division of responsibility rather than a competition between local and remote scientists.

Design dossier — protect scientific clocks and timestamps

Correlating samples, imagery, environmental data and instrument logs requires consistent time references. Clock drift or mixed time standards can make it difficult to reconstruct whether an atmospheric change preceded a measurement anomaly. Systems should record the time basis and synchronize or cross-calibrate clocks used in campaign data.

When delay-tolerant communications reorder files, embedded timestamps and stable identifiers preserve chronology. Scientific operations depend on time traceability even when the underlying question is geological rather than navigational.

Design dossier — verify the campaign with an end-to-end mock sortie

Before a high-value field campaign, crews can rehearse the sequence using representative terrain or a local test area: planning, labeling, imaging, sample handling, transfer, laboratory receipt and metadata ingestion. The exercise often reveals practical gaps such as inaccessible labels, overloaded gloves, software fields that take too long or ambiguous container numbering.

Correcting these issues before the real traverse protects both EVA efficiency and scientific integrity. Verification should cover the whole evidence chain, not just whether the instrument produces a reading.

Final synthesis for mission qualification

Final synthesis — a sample is evidence plus context plus history

A sample has scientific value only to the extent that researchers can reconstruct what it is, where it came from, how it was selected, what happened to it and which measurements were performed. Field context, custody, preparation and instrument configuration therefore belong to the evidence itself. The most impressive analytical precision cannot repair a broken identity chain. Campaign quality should be reviewed from the final conclusion backward to the station, asking whether every important inference can be traced to preserved observations and controls.

Final synthesis — local scientific autonomy is a designed operating mode

Autonomy does not mean the Mars crew ignores Earth expertise. It means the mission has already agreed which decisions must be made locally before Earth can respond, which thresholds authorize extra sampling or repetition, and which uncertainties require conservative preservation instead of immediate interpretation. Earth specialists then work on a slower cycle using transmitted data and can redirect later traverses. This division of time scales allows science to remain both collaborative and operationally executable.

Final synthesis — campaign success is information gained without consuming future options unnecessarily

A good campaign leaves the settlement with stronger explanations, well-documented samples, preserved archive material and a clear record of what remains uncertain. It does not maximize specimen count or instrument hours. The team should be willing to stop collecting redundant

material, postpone destructive tests and protect future opportunities when current evidence is already sufficient. Scientific discipline on Mars is partly the art of deciding what not to consume today.

Qualification notes

Qualification note — preserve negative results

A campaign should retain well-controlled negative measurements instead of discarding them because they appear uninteresting. A non-detection with known sensitivity can constrain hypotheses, guide future sampling and prevent later teams from repeating the same work. The archive should record detection limits, controls and sample context so absence of evidence can be interpreted correctly.

Qualification note — distinguish environmental change from instrument change

When a time series shifts, investigators should ask whether the environment changed, the sampling location moved, the instrument drifted or the processing pipeline changed. Reference materials, metadata and version control provide the evidence to separate those possibilities. This discipline is essential when long campaigns compare measurements across seasons and hardware maintenance.

Qualification note — close each campaign with unresolved questions

The final report should not merely summarize successes. It should list uncertainties that remain open, samples that deserve future analysis, missing comparisons and any operational limits that constrained interpretation. These unresolved questions become deliberate inputs to later traverses rather than being rediscovered from scratch.

Final evidence note

Scientific qualification should include enough reserve in time, containers, calibration material and archive capacity that an unexpected result can be checked rather than forcing the crew to choose between abandoning the finding and consuming the protected material budget. A campaign with no slack cannot investigate surprise, and surprise is often where the most valuable science begins.

Final archive note

Every campaign closure should verify that raw data, metadata, photographs, custody records and derived products are stored redundantly and linked by stable identifiers. The scientific result is not complete until another team can reconstruct the evidence chain without depending on the memory of the people who collected it.

Completion note

A final readiness review should confirm that the field plan, laboratory sequence and archive strategy still answer the same scientific question after all operational compromises have been incorporated. If route changes, instrument outages or lost samples have removed a critical comparison, the report should state that limitation explicitly rather than allowing the original hypothesis test to appear complete.

Interactive beginner glossary

These definitions emphasize traceability and decision use rather than dictionary wording.

- hypothesis — A proposed explanation that can be tested against observations or measurements.
- field station — A defined location where a planned set of observations or sampling tasks is performed.
- sampling plan — A documented strategy describing what will be collected, where, why and in what quantity.
- representative sample — Material selected to characterize a defined population, unit or condition rather than only an unusual feature.
- replicate — A repeated sample or measurement used to evaluate variability or repeatability.
- calibration — The process of relating an instrument response to a known reference.
- blank — A control expected to contain none of the target signal, used to detect contamination or background from the method.
- control — A comparison condition used to interpret the effect or signal being studied.
- standard — A reference material or value with known properties used to check measurement performance.

- metadata — Information describing the circumstances, configuration and provenance of a sample or data product.
- provenance — The documented origin and history of a sample or dataset.
- chain of custody — The traceable record of sample possession, handling, transfers and relevant conditions.
- subsample — A portion taken from a parent sample for a specific analysis or archive.
- archive fraction — Material deliberately preserved for future analysis rather than consumed immediately.
- non-destructive analysis — A measurement intended to preserve the sample substantially intact for later work.
- destructive analysis — A procedure that consumes or irreversibly alters some or all of the sample.
- instrument drift — A gradual change in measurement response unrelated to the true sample value.
- quality control — Checks used to detect measurement, handling or process errors and to judge data reliability.
- uncertainty — A quantified or described range of doubt about a measurement or interpretation.
- selection bias — Distortion caused by choosing samples in a way that does not fairly represent the question being studied.
- context image — A photograph showing a sample or observation in relation to its surrounding geological setting.
- station identifier — A stable code linking observations, images, samples and notes to one field location.
- trace contamination — A small introduced substance capable of confusing a sensitive measurement.
- planetary protection — Policies and practices intended to limit harmful biological contamination between planetary environments.
- sample integrity — The degree to which a sample preserves the identity and condition needed for its scientific purpose.
- field notebook — A structured record of observations, decisions, anomalies and interpretations made during field operations.
- raw data — Original measurement output before interpretation or derived processing.
- derived product — A result created by processing or interpreting raw measurements.

- campaign — A coordinated sequence of field and laboratory activities designed to answer a scientific objective.
- decision rule — A pre-agreed condition that authorizes or directs an operational choice when time or communication is limited.

Operational review checklist

- State a testable question before defining the traverse.
- Record context before disturbing or sampling a target.
- Make every planned sample serve an explicit comparison or hypothesis.
- Use blanks, standards, controls and replicates for different quality questions.
- Assign stable identifiers from field station through laboratory subsamples.
- Record instrument configuration and method version with every important result.
- Preserve chain of custody and environmental condition for sensitive samples.
- Sequence laboratory work to protect material needed for later or less reversible analyses.
- Define when surprising results require repeat measurement or an independent method.
- Give the local crew pre-agreed authority for time-sensitive field decisions.
- Protect archive fractions when future analysis may be more valuable than one extra current test.
- Plan crew-hours and EVA access around maintenance and safety obligations.
- Store raw data redundantly and preserve processing provenance.
- Label observation, inference and speculation separately in reports.
- Treat contamination control as both a scientific and operational design problem.

Field-science calculation studio: samples, uncertainty, time and traceability

Science operations become reliable when observations remain linked to location, time, instrument state, handling history and uncertainty. The calculations below teach that discipline without pretending that a single equation can certify scientific validity.

Formula A – packaged sample mass budget

Question. How much return or storage mass is committed by a set of individually packaged samples?

$$m_{\text{total}} = N \times (m_{\text{sample}} + m_{\text{container}})$$

Read aloud. “Total mass equals number of samples multiplied by sample mass plus container mass.”

Teaching calculation. For $N = 24$, $m_{\text{sample}} = 0.35$ kg and $m_{\text{container}} = 0.08$ kg: one packaged item = 0.43 kg; total = $24 \times 0.43 = 10.32$ kg.

Unit check. count $\times$ kg = kg.

Limit. Labels, secondary containment, tools, cold storage and transport cases may add mass outside this simple budget.

Formula B – station throughput

Question. At a sustained average pace, how many complete sample stations fit into the available science time?

$$N_{\text{max}} = \text{floor}(t_{\text{science}} / t_{\text{station}})$$

Read aloud. “N max equals the whole-number part of science time divided by time per station.”

Teaching calculation. If 150 min remain for science and a complete station requires 22 min, $150/22 \approx 6.81$. The floor function means only 6 complete stations fit without exceeding the time budget.

Check. $6 \times 22 = 132$ min, leaving 18 min. Seven stations would require 154 min, which exceeds 150 min.

Limit. Real station times vary; the average should not erase a required return reserve.

Formula C – concentration from measured mass and volume

Question. What concentration corresponds to a measured constituent mass in a measured volume?

$$C = m / V$$

Read aloud. “Concentration equals mass divided by volume.”

Teaching calculation. If an analytical exercise finds 18 mg of a constituent in 6.0 L, $C = 18/6.0 = 3.0$ mg/L.

Unit check. mg/L remains mg/L.

Reverse check. $3.0 \text{ mg/L} \times 6.0 \text{ L} = 18 \text{ mg}$.

Limit. This relation says nothing about sampling representativeness, instrument bias, detection limits or chemical speciation.

Formula D – relative measurement uncertainty

Question. How large is an absolute uncertainty compared with the measured value?

$$u_{\text{rel}} = u / |x|$$

Read aloud. “Relative uncertainty equals absolute uncertainty divided by the magnitude of the measured value.”

Teaching calculation. A result $x = 50$ units with stated standard uncertainty $u = 2$ units gives $u_{\text{rel}} = 2/50 = 0.04 = 4\%$.

Interpretation. The same ± 2 units would be 20% relative uncertainty if the measured value were only 10 units.

Limit. Relative uncertainty is not automatically the probability that the result is wrong; its statistical meaning depends on how u was defined.

Formula E – combining two independent uncertainty contributions by root-sum-square

Question. In a simple model with two independent standard-uncertainty contributions, what combined standard uncertainty follows from both?

$$u_c = \sqrt{(u_1^2 + u_2^2)}$$

Read aloud. “Combined uncertainty equals the square root of u_1 squared plus u_2 squared.”

Teaching calculation. If $u_1 = 3$ units and $u_2 = 4$ units: square them to obtain 9 and 16; add to obtain 25; square root gives 5 units.

Mental check. The result must be greater than either contribution alone but less than their simple sum of 7.

Limit. This form assumes independent contributions expressed on a compatible standard-uncertainty basis. Correlated errors require covariance terms.

Formula F – data return time

Question. How long does a data set require to transmit at a sustained net data rate?

$$t_{tx} = S / R$$

Read aloud. “Transmission time equals data size divided by data rate.”

Teaching calculation. An illustrative 12 gigabit data set sent at a sustained net 6 megabit/s requires 12,000 megabits / 6 megabit/s = 2,000 s $\approx$ 33.3 min.

Unit check. megabits $\div$ (megabits/s) = seconds.

Limit. Protocol overhead, contact gaps, retransmissions and changing link rate increase elapsed delivery time.

Formula G – conservative field radius from mobility time reserve

Question. In a symmetric out-and-back teaching model, how far may a team travel while preserving a specified travel-time reserve?

$$R_{\text{field}} \leq v_{\text{degraded}} \times t_{\text{travel}} / 2$$

Read aloud. “Field radius is less than or equal to degraded speed multiplied by travel time divided by two.”

Teaching calculation. If degraded travel speed is 3 km/h and protected travel time is 2 h total, $R_{\text{field}} \leq 3 \times 2 / 2 = 3$ km.

Why divide by two? The simple model allocates half the travel time to outbound travel and half to return.

Limit. Terrain, slope, obstacle avoidance, navigation uncertainty and asymmetric return conditions can make the real safe radius smaller.

Integrated science-operations exercise

A field team has 210 min outside. Travel out and back is budgeted at 80 min, setup and closeout at 30 min, and protected contingency reserve at 40 min. Each complete station requires 18 min. Compute science time and the maximum number of complete stations.

Solution. Science time = $210 - 80 - 30 - 40 = 60$ min. $N_{\text{max}} = \text{floor}(60/18) = \text{floor}(3.33) = 3$ stations. Three stations require 54 min, leaving 6 min. Four would require 72 min and would violate the stated reserve.

Field-science calculation laboratory: every sample consumes logistics and evidence capacity

A sample is not only a rock in a bag. It needs a known location, container, label, contamination history, analytical plan, storage allocation and chain of custody.

Returned sample mass budget

$$m_{\text{total}} = N \times (m_{\text{sample}} + m_{\text{container}})$$

Question. What mass is committed when a campaign collects many individually packaged samples?

Teaching scenario. Twenty-four samples average 0.35 kg each and each container/label system adds 0.08 kg. One packaged sample is 0.43 kg. Total = $24 \times 0.43 = 10.32$ kg.

Unit check. count $\times$ kg per item = kg.

Interpretation. Mass planning is part of science planning. It does not measure scientific value; a small, well-contextualized sample can be more useful than a heavier poorly documented one.

Chain-of-custody completeness

$$C = N_{\text{complete}} / N_{\text{total}}$$

If 23 of 24 samples have complete location, time, collector, seal and transfer records, $C = 23/24 = 0.958$, or 95.8%. That number is a traceability indicator, not proof that the records are correct. The missing record must still be investigated.

► Exercise — cache capacity

First-Man field science: a sample becomes evidence only if its history survives

A spectacular rock is not automatically a valuable scientific sample. The laboratory needs context: exact location, orientation, surrounding geology, collection tool, container, time, environmental observations and the sequence of every later transfer. Chain of custody protects interpretation. If two samples are swapped, warmed unexpectedly, exposed to habitat dust or relabelled ambiguously, expensive analysis can produce precise answers to the wrong question.

Observe

context, hypothesis,
imaging, coordinates

Collect

clean tool, controlled
quantity, unique ID

Preserve

container, temperature,
contamination control

Analyse

method, blanks,
standards, uncertainty

Field decisions should be driven by hypotheses, not souvenir value

Before EVA, define what observation would support or weaken each hypothesis. That determines which sites are worth reaching and which measurements should be made before disturbing the surface. A field crew that discovers an unexpected layer should be able to revise the plan, but the change must preserve time, consumables and return constraints.

Controls and blanks are part of the science. If an instrument detects an organic compound, a blank exposed to the same container and handling path can help distinguish the sample from contamination introduced by the system. Calibration standards reveal whether instrument response drifted. These apparently unexciting samples often determine whether a dramatic result is defensible.

Uncertainty should follow the result into mission decisions

A measurement reported as one exact number invites false confidence. The team should distinguish instrument resolution, calibration uncertainty, sampling variability and spatial heterogeneity. If two sites differ by less than the combined uncertainty, the correct conclusion may be that the data do not resolve a difference. “No resolved difference” is not the same as “the sites are identical.”

Exercise: protect scientific value during an EVA delay

The crew has collected three samples when a rover fault cuts remaining field time by forty minutes. One high-priority sample still requires contextual imaging and a blank; two low-priority targets remain untouched. The scientifically disciplined choice is usually to finish the evidence chain for the high-priority sample rather than rush through two poorly documented collections. Quantity of samples is not the mission objective; interpretable evidence is.

Chain of custody protects a scientific conclusion against mix-ups, contamination and undocumented handling. Pedagogical synthesis by Delta-Sierra from the primary sources cited in this course; schematic, not to scale.

Operational qualification lab: turn a field sample into defensible evidence

Field science is not complete when a rover or astronaut picks up an interesting rock. The scientific product is a chain of evidence: site context, observation, sampling decision, contamination control, identifier, transport, laboratory preparation, measurement, uncertainty and interpretation. A beautiful spectrum with weak provenance can be less valuable than a modest measurement whose history is completely known.

Design the traverse around questions, not photographs

Before departure, write the scientific question in a form that can be falsified or constrained. Then identify which observations would change the interpretation. A traverse should include targets, controls and decision points. For example, if the team is testing whether a layered deposit records repeated aqueous episodes, it may need samples from several stratigraphic positions, not merely the visually most unusual clast. Context images, orientation and relative position become part of the sample.

Primary-source bridge. NASA Artemis Science provides primary context for field science objectives and sample-driven exploration; NASA NTRS field-geology training material provides additional operational context. [NASA Artemis Science](#) · [NASA NTRS — Geology and Field Training](#).

Time on the surface is a shared resource. Walking or driving, documenting, sterilising tools, collecting, bagging, labeling and contingency reserve all consume the EVA clock. The plan should therefore distinguish “must obtain” observations from opportunistic science.

Usable field-station count inside a fixed science window

$$N_{\text{stations}} = \text{floor}((T_{\text{science}} - T_{\text{reserve}}) / t_{\text{station}})$$

1 – Concrete question

How many complete sampling stations can the team plan without consuming the protected return or contingency reserve?

2 – Intuition

Protect the reserve first, then divide the remaining science time by the time required for one complete station.

3 – Quantities

Define the science window, protected reserve and realistic station duration including documentation and sample handling.

4 – Formula

Subtract reserve from the science window, divide by station time and round down to a whole number of complete stations.

5 – Read aloud

“N stations equals the floor of science time minus reserve time, divided by time per station.”

6 – Symbols

N is a count; T_{science} is available field-science time;
 T_{reserve} is protected time; t_{station} is time per completed station.

7 – Pronunciation

“floor” means take the greatest whole number not larger than the calculated value.

8 – Units

Minutes divided by minutes gives a dimensionless count.

9 – Convention

The reserve is not a normal science allocation. Do not plan to consume it to make the schedule look complete.

10 – Why this relationship

Only time remaining after the reserve is protected can be committed to stations; partial stations do not satisfy the same documentation standard.

11 – Assumptions

The formula assumes similar station durations. Real traverses should carry separate times for complex stations.

12 – Unit check

$(\text{min}-\text{min})/\text{min} = 1.$

13 – Numerical case

Science window: $T_{\text{science}} = 180 \text{ min.}$

Protected return/reserve time: $T_{\text{reserve}} = 40 \text{ min.}$

Assignable field time = $180 - 40 = 140 \text{ min.}$

One complete station: $t_{\text{station}} = 27 \text{ min.}$

$140 \div 27 = 5.185\dots$

$N_{\text{stations}} = \text{floor}(5.185\dots) = 5 \text{ complete stations.}$

14 – Operations

First protect 45 minutes, leaving 165. Divide by 32. Round down because 0.156 of a station is not a complete documented station.

15 – Algebra check

Five stations consume 160 minutes, leaving 5 minutes beyond the protected reserve; six would require 192 minutes and would consume 27 minutes of the reserve.

16 – Mental estimate

Five 30-minute stations are about 150 minutes, so five is plausible and six is aggressive.

17 – Interpretation

The nominal plan should contain five complete stations, with opportunistic observations only if execution runs ahead.

18 – What it does not prove

It does not prove the route is safe, that communications remain available or that all stations have equal scientific value.

19 – Sensitivity

If dust or tool problems increase station time to 40 minutes, only four complete stations fit.

20 – Practice

Guided exercise. Compute the complete station count for a 180-minute science window, a 40-minute protected reserve and 27 minutes per station.

Detailed guided correction.

1. Assignable science time = $180 - 40 = 140$ min.
2. $140 \div 27 = 5.185\dots$
3. Only complete stations count, so $\text{floor}(5.185\dots) = 5$ stations.
4. Five stations use 135 min, leaving 5 min inside the science allocation plus the untouched 40-minute protected reserve.

Autonomous exercise. A traverse has candidate stations A=22 min, B=35 min, C=28 min, D=45 min and E=25 min. After reserving 50 min from a 190-minute field window, choose a set that maximises evidence value if A, C and E are high priority and B/D are medium priority.

► Autonomous correction – open after attempting the exercise

21 – Mission decision

Use the calculation to define a turn-back or skip-station rule before the team is under time pressure.

Chain of custody is part of the science

Each sample needs a unique identifier linked to location, context images, collector, tool state, container, time and subsequent transfers. When a container is opened or subsampled, the record should preserve which fraction went where. Blanks, controls and duplicate measurements help separate a real signal from contamination or instrument behaviour. The principle is simple: another competent investigator should be able to reconstruct what happened without relying on the memory of the original crew.

Qualification drill

Design a five-station traverse for a layered outcrop. One station must be skipped if the team loses 25 minutes early. State which station you would sacrifice and why. Then trace one sample from outcrop to instrument result, including the control sample that would reveal contamination introduced by the sampling tool. Your final interpretation must state which observation would make you reject your first geological story.

R61 field-science evidence chain: from traverse question to defensible archive

Field science on Mars should be designed so that another competent investigator can understand why a target was selected, how it was sampled, what may have contaminated it, which instrument state produced each measurement, and what uncertainty remains. The mission therefore treats provenance as part of the specimen. A spectacular sample with weak provenance can be less scientifically useful than an ordinary sample embedded in a rigorous chain of evidence.

Start every traverse with competing hypotheses

A traverse plan should state what observations would support or weaken at least two plausible interpretations. That changes behaviour in the field: the crew seeks discriminating observations rather than simply collecting interesting rocks. It also reduces confirmation bias because the team records evidence that contradicts the preferred story. A stop that cannot answer a defined question should compete explicitly against stops that can.

Primary-source bridge — Artemis Science. NASA's Artemis science material provides primary context for integrating science objectives with human surface operations. R61 carries that logic into Mars traverse planning and evidence capture. [Official source](#).

Calibration state belongs in the data record

Before and after a measurement sequence, record calibration checks appropriate to the instrument, environmental conditions, software version, operator and any maintenance or cleaning action. Instrument drift can imitate environmental change. If a spectrometer baseline moves after a dust event or thermal cycle, the science team must know whether the change belongs to Mars or to the instrument.

Contamination control should be designed as a branching decision tree

Separate tools and containers by cleanliness class where practical, document contact surfaces, and identify which analyses are most vulnerable to terrestrial material, lubricants, cleaning compounds or cross-sample carryover. A suspected contamination event should trigger quarantine and investigation, not silent deletion. Negative and ambiguous results remain part of the evidence chain because they constrain later interpretation.

Field notes need machine-readable structure and human context

Coordinates, time, sample identifier, image links, instrument settings and environmental data should be structured enough for search and automated correlation. But a short human narrative is still necessary: why the crew chose the target, what looked unusual, what changed from the plan, and what uncertainty the operator noticed. Structured metadata without context can preserve numbers while losing the reasoning that produced them.

Primary-source bridge — NASA Technical Reports Server field geology study. This NTRS record is already used by the course as a primary bridge for planetary field-science operations; R61 places the evidence-chain lesson next to the operational practice it supports. [Official source.](#)

Science triage must include the cost of evidence preservation

When EVA time, sample mass, power or data volume becomes constrained, prioritise not only scientific promise but also whether the sample can be documented and preserved correctly. A sample collected during a rushed return with broken provenance may consume scarce return mass without answering the intended question. The triage rule should protect the integrity of the best evidence rather than maximise sample count.

Qualification drill — a surprising result with a weak chain of custody

A sample produces an unexpected organic signature, but the container was handled after a glove change that is incompletely logged. The team should freeze interpretation, preserve all related blanks and controls, reconstruct the handling timeline, repeat analysis where possible and label the result with the unresolved contamination risk. The correct scientific behaviour is to preserve uncertainty explicitly rather than convert excitement into confidence.

Preserve the relationship between raw data and interpretation

The archive should retain raw or minimally processed data when feasible, the processing version used to create derived products, and the reasoning that turns a measurement into a geological interpretation. If a calibration or algorithm later changes, the team should be able to reproduce the older result and understand why the interpretation moved. This is especially important when evidence is unique and cannot be recollected easily.

Science return and crew safety share the same timeline

A scientifically valuable stop does not justify consuming the return reserve needed for a safe traverse. The science lead and EVA lead should therefore share explicit turn-back criteria. When time slips, protect the observations that answer the primary hypothesis first, then lower-priority sampling. The best field campaign is one that returns both the crew and a coherent evidence package.

Negative findings should change the next plan

If repeated measurements fail to support the expected mineral, structure or process, record that as a result and update subsequent target selection. Continuing to collect the same kind of sample because the team expects the preferred answer wastes scarce field time. A mature campaign uses negative evidence to redirect effort rather than hiding it in an appendix.

Conflicting measurements should trigger quality checks and repeat evidence before the mission changes its scientific conclusion. Pedagogical synthesis by Delta-Sierra from the primary sources cited in this course; schematic, not to scale.