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In search of signs of life on Mars with China's sample return mission Tianwen-3

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The aim of China's Mars sample return mission, known as Tianwen-3, is to collect at least 500 g of samples from Mars and return them to Earth around 2031. Here we summarize the scientific objectives of Tianwen-3 and discuss the concept of the mission, from selecting the payload to curating the sample. The mission aims to provide insights into nine scientific themes centred around the main focus of the search for extant and past life on Mars. These nine themes, together with requirements based on technical capabilities, inform the selection of the payload. We present preliminary studies on a full-chain protocol and the strategy for the selection of the landing site and detection of potential biosignatures in the returned samples. We also propose, in strict accordance with the Committee on Space Research's Planetary Protection Policy, an integrated plan for sample preservation and analysis. This plan involves the establishment of the Mars Sample Laboratory to conduct a comprehensive examination of the returned Mars samples and safeguard Earth against potential exobiological contamination.

Mars is the most promising planet for humanity's expansion beyond Earth, with its potential for future habitability and accessible resources. Unlike Earth, Mars has not experienced global plate tectonic movements and has not possessed a global ocean, preserving many of its ancient surfaces. Mars became dynamically inactive about 3.6 Gyr ago, when global volcanic activity largely ceased and the global magnetic field disappeared, leaving only weak regional magnetic fields[1,2]. Today, the Martian atmosphere is thin and composed mainly of carbon dioxide, with a pressure less than 1% of that on Earth. The surface of Mars is cold and dry with raging sand or dust storms, a planetary environment that is no longer habitable for life[3,4]. However, early Mars was more geologically active during the first 0.4 Gyr of its history[5], with internal heat supporting widespread volcanic activity, a thicker atmosphere and liquid water on its surface, suggesting that it may have been habitable in the past[6].

Over the past six decades, more than 40 Mars exploration missions have greatly enhanced our understanding of the planet's climate history and chemical diversity (Box 1). Orbiters have mapped the global distribution of hydrous minerals[7,8], while landers and rovers have detected methane, organic molecules and subsurface water ice, all of which indicate the potential for past habitability[9–11]. However, despite these advances, the question of whether life ever emerged on Mars remains unanswered[12]. Collecting samples from Mars could provide accurate data on the signs of life. Strategies for collecting Martian samples include obtaining Martian meteorites on Earth, as well as obtaining materials deposited on the surface, atmospheric dust and samples on Mars that can be recovered and analysed by instruments aboard a lander or rover[13–18].

Recognizing the scientific significance of sample return, international space agencies have prioritized Mars sample return (MSR) missions[19]. The joint NASA (National Aeronautics and Space Administration)–ESA (European Space Agency) MSR programme, initiated under the Planetary Science and Astrobiology Decadal Survey, aims to return approximately 600 g of Martian samples as early as 2031[20]. The mission, carried out in multiple stages, has already begun: the

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BOX 1

Important discoveries about Mars

In recent decades, analysis of high-resolution images from orbiters and on-site investigations by landers and rovers have considerably expanded our knowledge of the evolution of the interior, surface and climate of Mars. The most important scientific discoveries include:

- Ancient liquid water activity. Remote sensing and robotic investigations have confirmed that liquid water was once abundant on ancient Mars[38–40], as shown by the identification of fluvial valleys, deltas, alluvial fans and sedimentary layers. Although the exact volume of liquid water on the Martian surface remains undetermined, and the significance of subsurface water reservoirs is still debated, it is widely accepted that such water could support favourable conditions for the emergence, persistence and possible activity of life (enabling survival, maintenance, growth, or reproduction). These reservoirs, whether on the surface or underground, may have played a crucial role in sustaining habitable environments, especially in the early history of the planet. In these early liquid water environments on Mars, minerals such as siderite or gypsum would have evolved, depending on pH and the availability of key anionic components. Recent observations from the Perseverance rover in Jezero crater have also detected carbonate formation and water–rock interactions[41–44]. It is likely that these specific minerals formed during the active phases of ancient Martian lakes, particularly during the transition from the Noachian to the Hesperian period. After this period, the activity of liquid water on the surface may have decreased, and possibly shifted to the subsurface as the climate and hydrology of the planet changed.
- The distribution of clay minerals. Clay minerals on Mars are distributed throughout the planet and date mainly from the Noachian and early Hesperian periods (that is, about 4.1–3.5 Gyr ago)[7]. They are mainly distributed in the light-toned outcrops or scarps in the southern highlands, apparently derived from highly altered sedimentary rocks or pyroclastics[45]. Clay-bearing lacustrine environments on Mars offer several potential advantages for the emergence and persistence of life. The rapid formation or deposition of phyllosilicates in concentrated water may have formed protective mud layers for primitive microbial communities, shielding them from harsh surface conditions (such as cosmic rays). These clays also provide an ideal substrate for the storage and regulation of essential nutrients, creating a stable environment for life[46]. On a microscopic level, clays may have facilitated the uptake and utilization of extracellular nucleotides, supporting the biochemical processes necessary for early life to develop and thrive[47].
- Organic molecules and atmospheric methane fluctuations. The Curiosity rover discovered large organic compounds, such as thiophenes, aromatics and aliphatic compounds, in lacustrine sediments from about 3.5 Gyr ago in Gale crater[10]. This finding suggests that sulfurization may have preserved organic material on the surface of Mars. However, this does not rule out the possibility that these compounds were produced by ancient life or introduced by meteorite impacts, with later geological processes altering their traces. The background concentration of methane in the Martian atmosphere is between 0.04 and 0.8 ppbv, with seasonal peaks of 6–10 ppbv (refs. 9,38). The origin of this methane could be related to life, but abiotic geological, geophysical and geochemical processes on Mars could also be responsible[48].
- Volcanic activity. The global distribution of volcanic landforms on Mars was originally identified from Viking orbiter and Mariner 9 images[49]. Over more than 50 years of research, it has been determined that widespread volcanic structures may have formed in the Noachian or earlier (>4.0 Gyr ago) and accumulated to their present size, with most activity ceasing around 3.1 Gyr ago. Early volcanism provides insights into the formation of the Martian crust and the thermal evolution of the planet, as well as the early evolution of the Solar System[50]. Only a small amount of younger volcanism has been identified, centred on two large volcanic provinces of Amazonian age (<1 Myr ago), Tharsis and Elysium, suggesting the presence of heat sources in the local Martian mantle or significant impact events that may have caused magma upwelling[5].
- Striped magnetic anomalies. The magnetic anomalies on Mars were first discovered in 1999 by the Mars Global Surveyor, which orbited Mars at an altitude of about 450 km (ref. 51). The magnetic field of Mars exhibits a north–south dichotomy, similar to the gravity field and topography, with a high magnetic field strength in the southern highlands and low strength in the northern lowlands[52]. The magnetism of the Martian crust is at least an order of magnitude stronger than that of Earth, probably due to different magnetic mineral properties or a thicker magnetized layer[4]. The remanent magnetism of the crust shows reveals both positive and negative magnetic anomalies, suggesting that plate spreading and magnetic pole reversals may have occurred on early Mars similar to Earth. The strong extensive magnetization suggests the existence of a geomagnetic dynamo on early Mars, providing crucial insights into the planet's thermochemical evolution, as well as its tectonic and climatic history.
- The inner structure of Mars. Seismic data from the Insight mission provided the first detailed information on the internal structure of the red planet, revealing an average crustal thickness of 24–72 km (refs. 53,54), a lithosphere nearly 500 km thick and a possible low-velocity zone beneath the lithosphere[55,56]. The molten metallic core of Mars, with a radius of up to 1,830 km, suggests that the mineral composition of the Martian mantle may be comparable to that of Earth's upper mantle and the transition zone. However, Mars lacks lower-mantle materials such as bridgmanite, which is abundant in Earth's mantle[29,57]. The rocks on the surface of Mars are predominantly basaltic and less evolved than those on Earth[55,58]. Analysis of Martian meteorites shows that the hydrogen isotopic composition of the Martian mantle is similar to that of Earth, suggesting a common origin[59]. However, the Martian mantle contains a significantly lower water content than that of Earth. In contrast, the Martian crust contains a higher concentration of water and volatile components (such as F, S and Cl) than the mantle, with concentrations increasing near the surface. This distribution is probably due to degassing processes from the interior of the planet[60].

Perseverance rover landed in Jezero Crater in 2021 to collect and cache samples for future retrieval[21,22]. Meanwhile, Japan's Martian Moons eXploration mission[23], now scheduled for launch in 2026, will land on Phobos to investigate its composition and origins, offering indirect insights into Martian material exchange[24].

Following the success of the China's first Mars landing mission, Tianwen-1, the China National Space Administration is planning an MSR mission, called Tianwen-3. The mission plans to send a lander to Mars in 2028 and return samples 3 years later. This mission was first announced in June 2022[25]. It was later officially confirmed by the

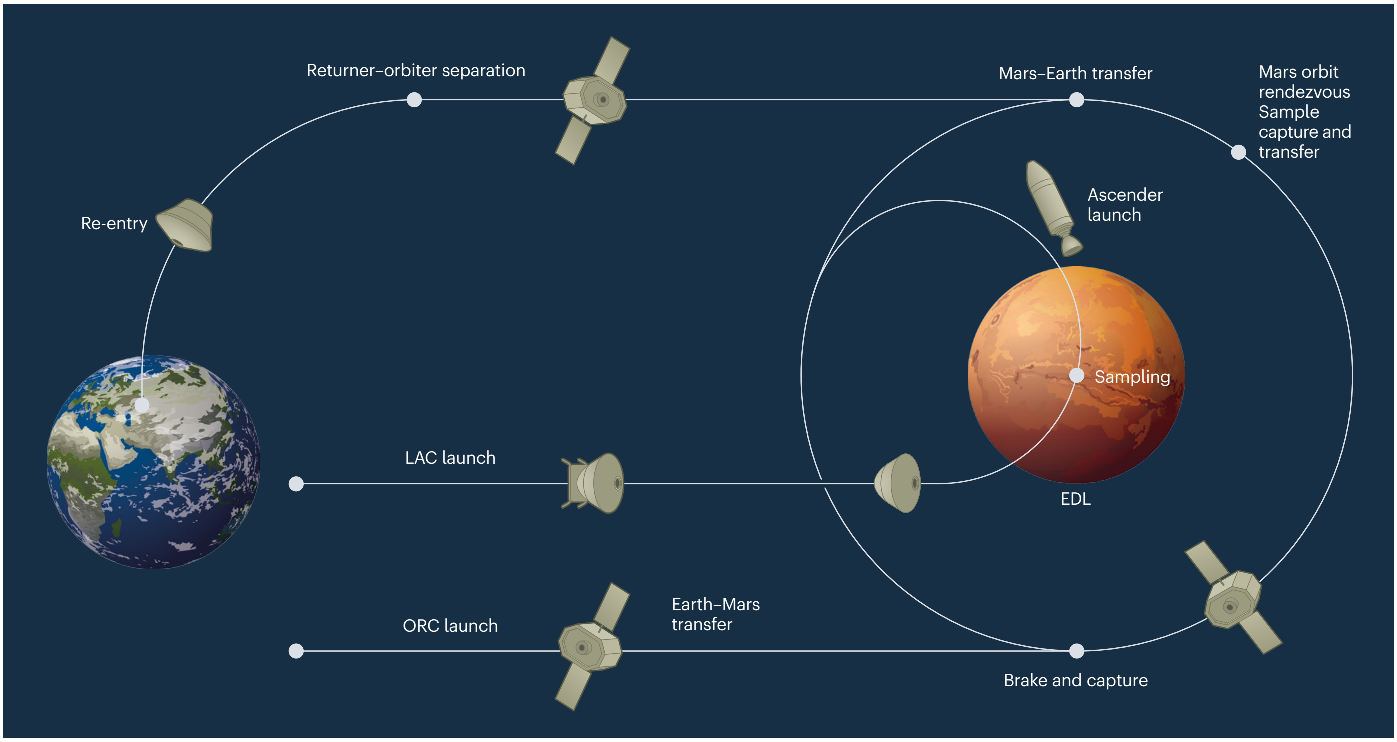

Fig. 1 | Mission profile of Tianwen-3. The bottom line represents the ORC departing Earth and entering Mars orbit. The middle line shows the LAC launching and landing on Mars. Once the lander collects samples, they will be transferred to the orbiter via the ascender. The top line indicates the return of the samples to Earth after collection.

China National Space Administration on 27 June 2024[26]. The primary scientific goal of this mission is to search for signs of life on Mars. The selection of potential landing sites that could contain biomarkers will be based on a comprehensive study through a so-called full-chain investigation strategy for the entire mission, which includes research blocks such as where to collect, what to collect, how to collect and how to analyse. In strict compliance with the Committee on Space Research's Planetary Protection Policy (hereafter referred to as the COSPAR Policy)[27], samples collected by surface shovelling and deep drilling weighing at least 500 g will be returned to Earth. The analysis of possible living organisms or biosignatures from Mars will be carried out in a dedicated laboratory with ultraclean and biocontainment zones.

Scientific objectives and payload of Tianwen-3

The scientific goals of China's Tianwen-3 mission include the search for signs of life, research into the Martian climate and the investigation of habitability in connection with processes of geological evolution.

The mission profile

The planned mission profile is shown in Fig. 1. To reduce the development risk, the success of the uncrewed extraterrestrial automatic sample return technology on the Chang'e-5 mission will serve as a benchmark for the design of surface and deep sampling systems[28]. The Tianwen-3 mission consists of two launches, one for the Orbiter-Returner-Combination (ORC), consisting of an orbiter and a return vehicle, and the other for the Lander-Ascender-Combination (LAC), which includes a lander, an ascent vehicle and a helicopter. The ORC will remain in a nearly circular orbit around Mars with an inclination angle of about 30° and an altitude of 350 km for about 11 months. The LAC will operate on the ground on Mars for about two months. During this time, the scientific payloads will be deployed on the lander. The entry, descent and landing (EDL) phase of Tianwen-3 will follow the same procedure as the successful landing of Zhurong[29] on Mars. Once the lander is in position, it will remain stationary. The target samples collected in the vicinity of the landing site will be packed and loaded into the ascent vehicle, which will lift off and dock with the return vehicle in Mars orbit. The landing sites selected for the LAC must meet the following criteria: 3 km altitude relative to the ellipsoid (International Astronomical Union parameters), latitude between 17° N and 30° N, slope no steeper than 8° and rock abundance ≤ 10%. The goal of the mission is to collect at least 500 g of Mars samples, including surface material and deep samples from the 2 m boreholes and mobile sampling with the helicopter. The encapsulation system for sampling from the Chang'e-5 mission will be adopted[30]. Sampling on the surface will be carried out by the robotic arm on the lander, which can take several samples within a radius of 1.5 m at the surface. The drill, mounted on the lander, will operate on site to reach a depth of 2 m and extract subsurface samples. Mobile sampling by helicopter will be used to gather rock samples. Ideal targets include different types of rock, rock fragments and loose soils.

Scientific goals

The main scientific goals of the Tianwen-3 mission include the search for possible traces of life on Mars, the exploration of the internal structure of Mars and the investigation of atmospheric circulation and escape processes, which constitute important contributions to our understanding of the habitability of Earth-like planets (Fig. 2). The scientific value of the samples to be returned from Mars was recently reassessed by the international MSR Samples and Objectives Team workshop[21]. The international workshop (72 participating nations) established seven scientific objectives of MSRs with corresponding sample/measurement requirements. Both the NASA–ESA MSR programme (primarily based on ref. 21) and China's Tianwen-3 mission align with these goals. An additional feature of Tianwen-3 is the collection of orbital data for an atmospheric study that will include the assessment of environmental hazards and resources for future crewed missions (Supplementary Table 1). The specific sample types for each scientific objective are also listed in Supplementary Table 1.

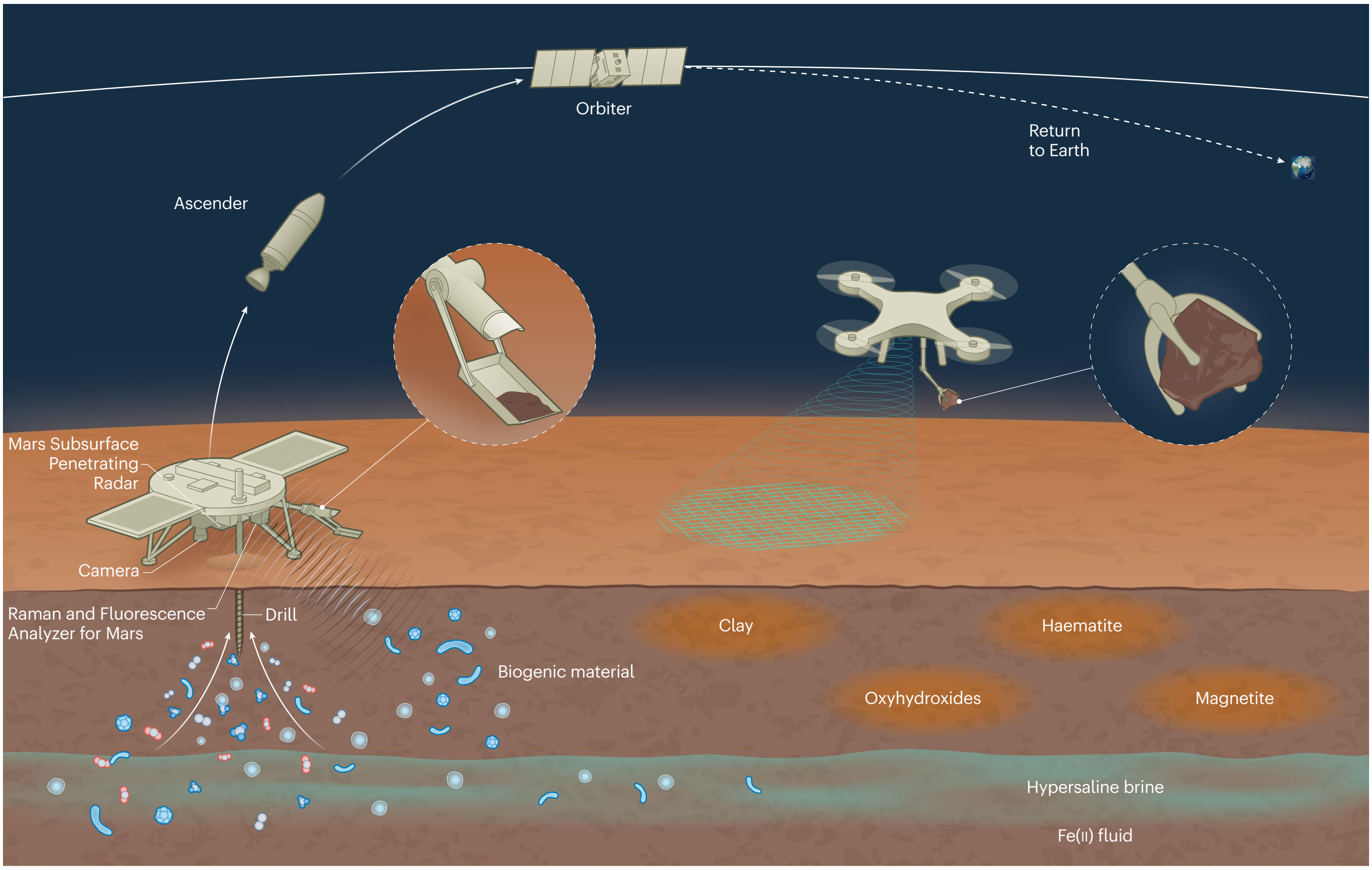

Fig. 2 | Schematic overview of the entire mission. The lander configuration with drilling and scooping payloads for biosignature analysis is shown on the left. The uncrewed drone, deployed for rock sampling at remote locations (operational range: >100 m), is shown on the right. All samples ascend to the orbiter. The layered structure in the lower right highlights potential compositional stratification within the Martian regolith (schematic representation, not to scale).

To achieve these objectives, we proposed nine specific themes for the Tianwen-3 mission (Box 2).

Basic payload requirements

Preliminary payload requirements have been proposed based on the scientific objectives of the Tianwen-3 mission, the technical capabilities of the Long March launchers and the maturity of the payload technology. These requirements aim to facilitate in situ investigations and the collection of deep and surface samples, as well as enable us to conduct comprehensive investigations of the Martian surface, atmosphere and space environment through multi-layered, multi-centre approaches.

The preliminary proposed payload for the lander includes the Mars Subsurface Penetrating Radar and the Raman and Fluorescence Analyzer for Mars. The Mars Subsurface Penetrating Radar is designed to provide information on the structure of the shallow subsurface in the study area, help in the selection of drilling sites and monitor drilling operations. The detection depth is 2 m or deeper, and the depth resolution is in the centimetre range. The Raman and Fluorescence Analyzer for Mars combines Raman and fluorescence spectroscopy with microscopic multispectral detection, enabling microscopic in situ measurements of materials on the Martian surface. It can determine the composition of silicates, oxides, organic compounds and hydrated minerals, and thus help with sample selection. Its wavelength range extends from the ultraviolet to mid-infrared region.

Proposed payload options for the orbiter include the Precipitating Energetic Neutral Atom and Aurora Analyzer and Mars Orbiter Vector Magnetometer, while those for the returner include the Mid-Infrared Hyperspectral Imager and Mars Martian Multispectral Camera. The Precipitating Energetic Neutral Atom and Aurora Analyzer is designed to measure the energy, flux, composition, direction and spectral properties of depositing energetic neutral atoms and their relationship to Martian proton auroras. It can distinguish between H, He and O compositions. The Mars Orbiter Vector Magnetometer will measure the fine structure of the Martian magnetic field and ionosphere, with a dynamic range of 0–10,000 nT. It inherits the design of the magnetometer on the Tianwen-1 orbiter[31,32]. The Mid-Infrared Hyperspectral Imager can measure the profiles of H_2O and HDO and determine the D/H ratio in the Martian atmosphere. This instrument will cover the absorption range of water in the mid-infrared region and provide important data on the composition of the Martian atmosphere. The Mars Martian Multispectral Camera will primarily be used for monitoring Martian dust, forecasting dust conditions and ensuring the safety of landing and ascent operations on the Martian surface. The international collaboration framework comprises three pillars: strategic payload allocation (20 kg), open data/sample sharing protocols and multinational mission roadmaps. These efforts will involve other countries and international organizations to maximize the achievement of scientific goals[33].

Search for evidence of life and selection of the landing site

The search for evidence of life on Mars is a priority in all international scientific exploration of Mars (Box 3), although there are still significant gaps in our understanding of the concept and the practice of exploration. To address these gaps, the individual elements of exploration need to be clearly defined, the underlying scientific mechanisms understood and the possible outcomes analysed. This comprehensive

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BOX 2

Scientific themes for the Tianwen-3 mission

By combining the scientific goals, technical feasibility and scientific payload capabilities, we identified nine key scientific themes:

- **Characteristics, preservation and significance of signs of life**. We will search for fossilized organisms and remains, analyse the properties of organic compounds and measure elements and isotopes associated with life. The search for traces of life will focus on identifying and distinguishing potential biogenic structures under the microscope, including iron oxide, carbonates, sulfates and phosphate minerals[61]. Analyses of organic compounds will target molecules directly relevant to biochemistry, such as amino acids, nucleotides, amines and thermally resistant biomarkers including hydrocarbons, lipids and kerogen. The study of essential elements and their isotopes will focus primarily on the carbon isotope system, the complex sulfur isotope system and the occurrence and isotopic composition of nitrogen, phosphorus and trace elements.
- **Development of aqueous surface environments**. By combining the returned samples with existing exploration data, we will attempt to reconstruct the history of surface water activity on Mars, measure the physical and chemical properties of water in these reservoirs and assess their ecophysiological significance. Specific research methods include analysing the water content and isotopic signatures of hydrated minerals in sediments, investigating the microstructure, mineral composition and distribution of isotopes and chemical elements in sediment clasts and exploring the coupling between surface water morphology types, geologic units, spatial distributions, ages of formation, durations, climatic environments and subsequent alteration processes.
- **Atmospheric dust and water activity on Mars**. Using the returned samples, various sources of observational data and numerical simulations, we will focus on the processes of interactions between the atmosphere, water and rocks on Mars to understand the coupling mechanisms between dust and atmospheric water vapour, and the transport of energy and matter. The altered minerals and atmospheric components contained in impact glasses in the returned samples could shed light on their historical evolution in the Martian atmosphere. To assess the triggers and spatial characteristics of dust storms and their contribution to thermal escape from the upper atmosphere, we plan to study the spatial and temporal distribution patterns of atmospheric activity, including vortices, circulation patterns and dust devils. We will also study the spatiotemporal distribution and vertical transport of water vapour to understand its responses to material distributions, atmospheric fluctuations and circulation patterns.
- **Solar wind and the escape of the Martian atmosphere**. The interaction between the Martian upper atmosphere and ionosphere and the solar wind will be investigated, with a focus on how the neutral particles and ions influence atmospheric escape. Using multiple data sources collected by the orbiter, we will investigate the variations in parameters such as the interplanetary magnetic field, the ion plasma of the solar wind, high-energy particles and the magnetic field and plasma within the Martian space environment. This analysis aims to uncover the evolutionary patterns of the Martian upper atmosphere and space environment to gain a deeper understanding of the mechanisms driving atmospheric escape. We will also investigate how atmospheric escape varies with different types and intensities of dust storms to assess their impact on the long-term evolution of the Martian atmosphere.
- **Spatiotemporal evolution of water and volatiles on Mars**. The returned samples, supplemented by Martian meteorites of different ages, will be used to determine the water and volatile contents of different materials (such as melt inclusions, hydrated minerals and nominally anhydrous minerals) and their isotopic compositions. This analysis will reveal the presence of water and volatiles from Earth's mantle. By integrating geochronological and geochemical analysis of the rocks, we will systematically investigate the water and volatile contents in Martian samples of different ages and from different source regions to trace their evolutionary history. In addition, we will use multi-isotope tracing systems (for example, hydrogen, chlorine, sulfur) to elucidate the degassing processes and the extent of magmatic rock formation on Mars during intrusion, crystallization and impact metamorphism.
- **The nature of the Martian crust**: Infrared spectroscopy measurements of the returned samples will serve as the basis for the creation of a correlation model of the spectral data on three levels: Orbiter, Lander and samples. This model will be used to calibrate the global orbiter and lander data and will facilitate the identification of the composition of the Martian crust. By analysing the structural, compositional and in situ characteristics of the samples and their environments, we will investigate geological structures, topographic features and geochronology. This analysis will help us to trace the origins of the samples and understand the geological evolutionary processes recorded in the samples.
- **Composition and evolution of the ancient Martian mantle**. Based on the geochemical properties and geochronological analysis of the returned samples, in conjunction with the study of Martian meteorites, we can determine the chemical composition and crystallization differentiation of magmas from different stages of ancient Martian magmatic activity. This research will allow us to draw conclusions about the evolutionary history of ancient magma. By selecting primitive mafic samples from Earth's mantle that have not undergone subsequent geological transformation, detailed analyses of the most important trace elements and the associated isotope systems will be carried out. These analyses will help to determine the rock types and properties of the regions of origin of the Martian mantle, and provide insights into the evolution of the composition and processes of differentiation in the Martian mantle.
- **Impact flux and geological activity in the history of Mars**. The returned rock and soil samples can be used to accurately determine the isotopic age by analysing uranium-bearing minerals such as zircon, phosphates and glasses. In combination with remote sensing data from various sources, these analyses can trace important geological processes in the regions of origin of the samples, such as impacts and volcanic activity. This approach enables the study of the impact history of the geologic units in the source region and will help to estimate the impact flux on the surface of Mars and refine the timeline of geological activity. By calibrating the statistical dating curve for the frequency distribution of craters, scientists can more accurately determine the lithologic age of Martian rocks, providing a more precise timeline for other geological activity and their evolutionary patterns on Mars.

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- **The differentiation of the Martian core and mantle and the internal evolution of ancient Mars**. By combining the analysis of the returned igneous rocks with the compositional data from the rover, we can develop a model for the formation and evolution of the early Martian layers and explore chemical evolution processes in the planet's interior. The chemical and mineralogical properties of different rock samples will be studied to understand the impacts and other external dynamic processes that have shaped Mars over time. The study of slightly altered or unaltered igneous rocks will help to constrain the original composition and processes involved in the formation and early evolution of Martian magma. In addition, elemental and isotope analyses, high-temperature and high-pressure experiments (such as melting, equilibrium crystallization and fractional crystallization) and in situ microscopic measurements will allow us to elucidate the mechanisms of core–mantle differentiation and identify alteration processes affecting the Martian crust, including impacts and secondary alteration.

BOX 3

The priorities of Mars exploration in the next decade

Search for life on Mars. Since over 60% of the Martian surface is more than 3.5 Gyr old, and clay minerals indicate past environments with liquid water, Mars has probably preserved evidence of conditions suitable for life in its early history. Considering that life originated on Earth about 3.8 Gyr ago, these efforts focus on the study of life forms similar to those on Earth, the potential for life in extreme extraterrestrial environments and the identification of biological and trace fossils, biogenic organic compounds, biogenic elements and isotopes, and inorganic substances that may indicate the presence of life[62].

- **Interactions between the space environment, atmosphere, topography, surface material and internal structure of Mars**. This includes investigating the mechanisms behind dust–water fluctuations in the Martian atmosphere, their effects on the vertical transport of water vapour and energy[63,64], and the influence of the space environment and solar wind on atmospheric escape[65]. In addition, investigating water-formed landforms and hydrogeologic features will help to identify the essential elements and physicochemical conditions required for life. This provides information about habitable geological environments on Mars[66]. Determining the timing and reasons for the cessation of the magnetic dynamo will also shed light on the internal thermal state and its impact on the planet's water supply[67]. In addition, studying the unique geological structures and evolutionary processes on Mars is critical to understanding its thermal history and its implications for water storage[68].
- **Development of advanced exploration techniques crucial for conducting high-quality in situ investigations and collecting Martian samples for analysis in terrestrial laboratories**. International missions for in situ exploration of Mars face significant limitations due to factors such as payload mass, power and volume, which have a negative impact on the sensitivity, resolution and pretreatment of the analysed samples. Therefore, capturing biosignatures and atmospheric data and studying the evolution of the Martian geologic and aqueous environment with high precision remains a major challenge. The synergy between in-orbit investigations and ground-based laboratory analysis will be critical to the success of future scientific research on Mars.
- **Geochronological, petrological and palaeontological features of Martian samples can help in the search for evidence of fossils, metabolites or isotopes associated with life**. The use of returned samples, with detailed knowledge of their collection areas, types and geological contexts, can overcome the limitations of studies based solely on Martian meteorites[69]. This approach enables the collection of a wider range of samples, such as sedimentary rocks, and allows the calibration of absolute ages using impact crater dating curves. It will also help to better constrain the chemical composition of the Martian crust, correct remote sensing and in situ data on the composition of the crust[70] and investigate the mechanisms behind the heterogeneity of the Martian mantle. In addition, this research will improve our understanding of the long-term petrological and geochemical properties of Mars, the early differentiation process between the crust and mantle and the thermal evolutionary history[71,72].

approach will also be very helpful in selecting landing sites and ensuring that the selected sites have the greatest potential to find traces of past or present life on Mars.

A full-chain investigation strategy for the MSR mission

Given that the Tianwen-3 lander equipped with the drill is stationary, the landing site must be carefully selected on the basis of high-resolution slope, roughness and mineralogy data. To maximize the scientific value of the samples, thorough studies are required at all exploration stages, including where to collect, what to collect, how to collect and how to analyse. This full-chain investigation strategy addresses all aspects, from mission planning to sample analysis in a specialized laboratory.

Where to collect. A comprehensive assessment system will be developed to identify areas with a high probability of traces of life on Mars. This system will analyse key regional characteristics that enhance the preservation of biosignatures, including specific geologic formations, sedimentary layers or mineral deposits that may have protected organic material or fossil life forms over time.

What to collect. Research will focus on the astrobiology of the targeted Martian environment and determine which types of sample (such as rocks, soils or certain minerals) are most likely to contain or preserve traces of life.

How to collect. To support the technical planning of sample collection, this aspect focuses on determining the particle size requirements for various Martian materials and the appropriate drilling depth to access subsurface samples. These factors are critical to ensure that the samples collected are representative and scientifically valuable.

How to analyse. This phase focuses on the development of advanced techniques to identify potential biological structures, such as fossils or microscopic features, in the returned samples. In addition, methods to detect and analyse biogenic organic compounds and essential elements

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Table 1 | List of large areas with potential landing sites that could be considered

Potential landing site	Longitude	Latitude
McLaughlin Crater	22.3–22.5° W	21.89–21.9° N
Oxia Planum	24.4–24.41° W	18.26–18.5° N
Mawrth Vallis	19.62–21.3° W	23.4–25.27° N
Oyama crater	19.8–21.1° W	23.4–24.0° N
Becquerel Crater	8.3° W	22.1° N
Nili Fossae	73.3–79.4° E	18.1–29.4° N
Kasei Valles	53.0–61.4° W	25.6–27.9° N
Around the Tianwen-1 landing area	109.7–112.3° E	20.4–25.2° N
Simud Valles	37.2–39.0° W	10–21° N
Isidis Planitia	89.5° E	21.7° N

and determine their isotopic compositions will be developed to assess the presence and origin of materials associated with life.

Preliminary selection of landing sites

The selection of the landing site for the Tianwen-3 mission is based on technical capabilities and scientific values. As a result, the chosen site should favour the emergence and preservation of evidence of traces of life. This requires the simultaneous presence of vital elements, a suitable solvent, sustainable energy sources and favourable climatic conditions—all of which must have existed over a sufficiently long period of time.

We began with 86 preliminary landing sites (Supplementary Table 2), and the top candidate regions were near Kasei Valles, McLaughlin Crater, Oyama Crater and Utopia Planitia (Table 1). The diversity of landing site candidates provides a rich variety of geological contexts for exploration. These ancient geologic formations include various environmental types such as surface and subsurface hydrothermal and sedimentary environments, as well as diagenetically altered regions. A large amount of representative Martian minerals have been discovered in these areas, with over half of the potential landing sites having exposed clay minerals. This provides favourable environments to study the local history of the water cycle and obtain possible biosignatures.

The habitability of the provisional land ellipses will then be examined in detail. This analysis will focus on the duration and extent of the presence of liquid water, the distribution of aqueous minerals, the sedimentary environment, the stratigraphy, the regional palaeoclimate and water–rock interactions. The assessment will identify the specific conditions that may have favoured the existence and development of life. Critical sub-areas will then be selected as potential landing sites and suitable locations for environmental sampling within these areas will be identified.

Laboratory plan for sample preservation and analysis

Although we expect the samples returned from Mars to contain only evidence of the expected life that once existed on Mars billions of years ago, we will still set up a laboratory to quarantine the suspected Martian life and ensure the highest level of biosafety. To prevent possible contamination of the terrestrial biosphere by living Martian life and to avoid false positive results due to cross-contamination with terrestrial microorganisms, it is essential to set up a dedicated laboratory for the preservation and analysis of the returned Martian samples. This laboratory must also maintain high standards of cleanliness with the highest level of biocontainment and analytical capabilities. It should be able to protect Earth's biosphere and keep samples in pristine condition, as well as contain essential analysis functionalities to examine the physical properties of solid samples, analyse gas and volatiles and

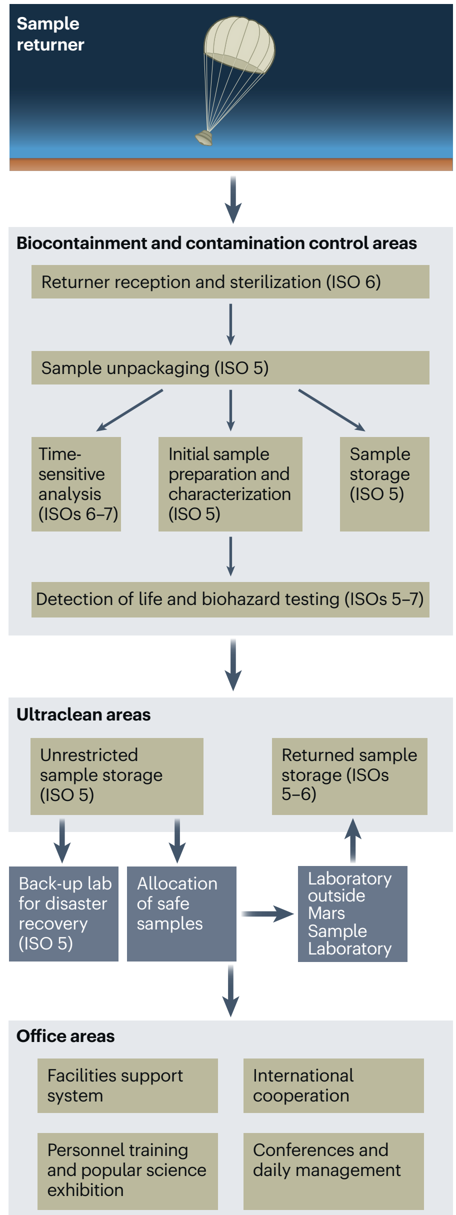

Fig. 3 | Functional zones of the Mars Sample Laboratory. The arrows indicate the processes of sample reception, storage and handling. Three distinct zones are defined by ISO classification requirements: (1) Biocontainment and Contamination Control Zones (ISOs 5–7) for returner reception/sterilization (ISO 6), sample unpackaging (ISO 5), time-sensitive analysis (ISOs 6–7), initial preparation/characterization (ISO 5), storage (ISO 5), and life/biohazard detection (ISOs 5–7); (2) Ultraclean Zones (ISOs 5–6) dedicated to unrestricted (ISO 5) and allocated sample storage; and (3) Office Zones, exempt from specific ISO requirements, supporting facilities, international cooperation, personnel training, and management.

detect possible signs of life. At present, there is no laboratory anywhere the world that is specifically designed to handle and analyse samples from Mars, where life is suspected.

Planetary protection

China's MSR mission is classified as a Class V restrictive return mission[34], which requires stringent measures to prevent potentially living life (presumably microorganisms) from being contaminated by Earth's biosphere (Forward Planetary Protection) and, more importantly, to protect Earth from an invasion of Martian life (Backward Planetary Protection). Forward Planetary Protection includes ground development, on-orbit flight, sample collection, encapsulation and transfer from the Martian surface, while Backward Planetary Protection includes the EDL, sample collection and ground handling phases. To preserve the pristine condition and scientific value of the Mars samples, it is critical to prevent contamination by biological, organic and inorganic materials from Earth. Therefore, the procedures for unpacking, handling, preservation and initial analysis of these samples must be performed in a controlled laboratory environment. In addition, the detection of life and biological risk assessments should be performed before conducting further scientific analysis or releasing samples.

Functional zones of the Mars Sample Laboratory

Cleanrooms are classified on the basis of the concentration and size of airborne particles per cubic metre according to the International Organization for Standardization (ISO) 14644-1 standard[35]. These classifications range from ISO 1 to ISO 9, with ISO 1 being the cleanest, allowing the fewest particles, and ISO 9 being the least stringent, although still much cleaner than typical environments. The core functions of the Mars Sample Laboratory include receipt and sterilization of the sample return capsule, step-by-step unpacking, pre-processing, sample collection, preparation, time-course and some sterilization-sensitive analysis, and biosafety evaluation and testing. All of these activities must be performed within the ultraclean and biocontainment zones (Fig. 3). Once biohazard testing confirms that the returned Mars samples pose no risk to Earth's biosphere, the Biosafety Protection Zone can be converted to a higher-grade cleanroom laboratory to reduce overall operating costs. The containment and cleanliness levels of the laboratory will comply with MSR Planning Group Phase 2[36,37]. In addition, the laboratory will support tasks such as the training of specialist staff, the promotion of international cooperation and scientific public relations work.

The Mars Sample Laboratory will perform the following six main functions:

(1) Bidirectional isolation of Mars samples: this includes biocontainment and contamination control measures to isolate Mars samples and the terrestrial environment in the core zones of the laboratory.
(2) Processing and storage: this phase includes dust removal, X-ray computed tomography and unsealing of samples. The samples are then categorized for scientific research and permanent storage.
(3) Time-critical analysis: volatile substances, such as gases, are analysed as quickly as possible to capture their volatile properties.
(4) Analysis of basic information: this includes determining the physical and chemical properties of samples, rock and mineral characteristics and other relevant data.
(5) Biosafety assessment: biological metabolites will be detected, and a series of biological experiments conducted to assess potential risks.
(6) Geocontamination assessment: at this stage, witness plates should be used to record the contamination environment of each sample. In addition, a small number of samples will be evaluated to avoid false positives in the search for traces of life, as required by COSPAR Policy.

Conclusions

China announced the Tianwen-3 mission in 2024, which aims to search for evidence of life on Mars. The plan is to launch the rockets in 2028 and bring samples back from Mars in 2031. A drill mounted on the lander will penetrate to a depth of 2 m to collect several grams of subsurface samples, while a robotic arm will gather more than 400 g of surface material from the landing site. Related research has commenced within the framework of a comprehensive full-chain strategy, which involves exploring various analogous environments to optimize payload design and identify the landing site with the highest scientific value.

In both the Forward Planetary Protection and Backward Planetary Protection phases, strict Earth protection measures will be taken with the returned samples to prevent contamination and avoid false positives in the search for traces of life, thus fulfilling COSPAR Policy. The Mars Sample Laboratory will prioritize the protection and scientific integrity of the Mars samples while ensuring the safety of Earth's biosphere. The Mars samples and exploration data will be used to further investigate the composition of Martian materials, the differentiation processes of its core–mantle–crust structure and the mechanism of atmospheric escape, which will ultimately improve our understanding of the habitability of Mars and its evolutionary history.

The Tianwen-3 mission proposes a comprehensive scientific application model that seamlessly integrates core functions including the pursuit of scientific objectives, sample examination, on-orbit exploration support, payload configuration and development, and Mars sample storage and examination while maintaining the highest biosafety standards. This model not only enhances research capabilities related to the origin of life, but also creates a solid foundation for future scientific applications, including the search for extraterrestrial life and the establishment of an in situ Mars research station for astronaut activities.

The exploration of Mars is a collective endeavour for all of humanity. The Tianwen-3 mission is committed to win–win cooperation, harmonious coexistence and shared prosperity through international cooperation. It actively seeks international partnerships through various channels and at various levels for joint scientific research, landing site selection and scientific payload development and testing. This approach aims to create a platform for the scientists, technicians, engineers and other specialists involved in the exploration of Mars to collaborate and to promote scientific progress and innovation at the frontiers of science.

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Competing interests
The authors declare no competing interests.

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