Origin of the elements - Cosmochemistry

“The primary purpose of geochemistry is on the one hand to determine the composition of the Earth and its parts, and on the other to discover the laws which control the distribution of individual elements” - V.M. Goldschmidt, 1933

Before you do that you need to understand the origin of the elements, and how the elements that make up the earth got there in the first place.

I. The Big Bang
The universe is currently believed to have started with the explosion from nothing of a “primeval fireball” which contained all the energy and matter in the universe. A few minutes after the Big Bang started the universe all there was in terms of elements was hydrogen (including the isotope deuterium) and helium, but mostly just the single proton hydrogen.
How did all the other elements come into existence?

II. Nucleosynthesis
Other elements were manufactured through nucleosynthesis inside stars. This is basically fusion of small atomic nuclei to make bigger ones. In the process they release energy which fuels the star. Elements up to Iron form by fusion. Elements larger than iron form by neutron capture

Now we know how elements and isotopes are created, what happens next? The newly-formed elements in their various isotopes are ejected into the interstellar medium. These new atoms form dust and molecules in space and are incorporated into new star systems, planets and presumably us. Hence we are all made of stardust.
The Sun is not a first generation star. The first generation stars were made only of hydrogen and helium, and therefore did not have any material with which to form planets. The demise of these old stars provided the building blocks for the sun and it’s planets. Actually it is unlikely that the sun is even a second generation star, since meteorites contain dust grains from second generation stars which must have expired before their dust could be included into the solar system

III. The Solar System
The solar system formed from the collapse of a cloud of gas and dust. Initially there would have been a central proto-star with a disk of dust and gas around it, out of which the planets formed. This is known as the Solar nebula.

We have the sun, which is a typical star in its main sequence of evolution. There are nine planets: 4 rocky or Terrestrial Planets; 4 gas giants or Jovian planets; and the least known outer planet Pluto. The terrestrial planets and the Jovian planets are separated by the asteroid belt. And somewhere way out beyond Pluto are the Kuiper belt and the Oort cloud where comets are born.

The terrestrial planets are small and rocky. The Jovian planets are large and gassy. It is clear that the formation circumstance for the terrestrial planets is different to that of the Jovian planets, probably partly due to their distance from the proto-star and therefore temperature.
IV. Meteorites
Meteorites are classified into 3 major groups: stony, stony-iron and iron. Stony meteorites are mainly made up of silicate minerals, while iron meteorites consist largely of an iron-nickel alloy. Stony-irons have considerable quantities of both silicate minerals and the iron-nickel alloy.

The majority (over 90%) of all meteorites are stony. These can be further classified into three subgroups:
1. Ordinary Chondrites, which have chondrules - mm-sized round masses within the matrix of the rock.
2. Achondrites, which do not have chondrules - but are otherwise similar in composition to the Ordinary Chondrites.
3. Carbonaceous Chondrites, which are characterized by their content of organic compounds, water and volatile elements. These are compositionally distinct from the Ordinary Chondrites. In particular, many of the matrix minerals in carbonaceous chondrites are either hydrous or stable only at relatively low temperatures, while the ordinary chondrites consist only of refractory minerals. The carbonaceous chondrites also contain tiny presolar grains. These grains have isotopic compositions which indicate that they formed outside the solar nebula and have not been altered by the formation of the solar system. Therefore, it is clear that the carbonaceous chondrites have not been significantly heated since their formation, therefore they are relics of the early solar system.

The ordinary chondrites can be further subdivided into groups based on their iron content. Likewise the carbonaceous chondrites can be subdivided into groups based on their exact mineralogy.

It is also possible to classify meteorites according to whether they have been differentiated or not. That is, the parent bodies from which the meteorites come can either suffer melting and differentiation into crust, mantle and core, like the earth, or they can remain undifferentiated. The achondrites, stony-irons and iron come from differentiated parent bodies, so that:

a) achondrites represent the crust and mantle of a terrestrial-type planet
b) stony-irons represent the mantle/core boundary
c) irons represent the core.

The chondrites, both ordinary and carbonaceous, come from undifferentiated parent bodies. Ordinary chondrites have undergone some metamorphism, while the carbonaceous chondrites are essentially the same as when they formed in the solar nebula. Therefore, the ordinary chondrites are expected to have elemental abundances for refractory elements of the early solar system, while the carbonaceous chondrites have elemental abundances of the early solar system for both refractory and volatile elements*. In fact some carbonaceous chondrites are very similar in composition to the sun.

V. Conclusions
I. The only element made in the Big Bang were hydrogen and helium.
II. Other elements are produced in stars
   a) fusion ("burning") produces elements up to iron; b) heavier elements are produced by neutron-capture.
III. Isotope stability depends on the nucleus: paired neutrons and paired protons are more stable than single nucleons.
IV. The Solar system can be split into the small rocky terrestrial planets and large gas giants or Jovian planets.
V. Meteorites can be classified as differentiated or undifferentiated. Differentiated meteorites give information on planet structure and formation as they represent the crust-mantle and core of differentiated planets. Undifferentiated meteorites give us a measure of the composition of the solar nebula from which the solar system formed.

Most meteorites have ages around 4.55 billion years.
The Moon is compositionally strange and is thought to be mostly made up of an impacting body that hit the young earth.

*although these meteorites are deficient in H and He compared to the bulk solar system composition.