Exploring Meteorite Landings On Earth

1 Objectives

I would like to explore the various locations on Earth that meteorites have landed and the materials in which these meteorites are made of. Are there any new elements that were discovered from these "space rocks"?

1.1 Aims

- Locations of known meteorite landings on Earth
- Material composition of meteorites found

1.2 Background

Meteor, meteoroid, meteorite. Are they all the same thing, or is there a distinct difference between them? According to NASA (2022):

> They’re all related to the flashes of light called “shooting stars” sometimes seen streaking across the sky. But we call the same object by different names, depending on where it is.

> **Meteoroids** are objects in space that range in size from dust grains to small asteroids. Think of them as “space rocks."
>
> When meteoroids enter Earth’s atmosphere (or that of another planet, like Mars) at high speed and burn up, the fireballs or “shooting stars” are called **meteors**.
>
> When a meteoroid survives a trip through the atmosphere and hits the ground, it’s called a **meteorite**. [1]

1.3 Relevance

Scientists/Meteorologists need to document and study these meteorites for several reasons. One of those reasons is so that we can better understand our solar system and the planets that dwell in it. Many of these planets, including our blue Earth, were formed billions of years ago by enormous asteroids colliding into each other. It is theorized that Earth's moon is one of the many debris that were created when these asteroids collided into Earth.

Another reason is that there could be a possibility of discovering a new element within the composition of the meteorites.

1.4 Data

Origin of the data set

The dataset is a CSV file taken from NASA. [2]

The dataset contains the following column iD's:

- **name**: the name of the meteorite (typically a location, often modified with a number, year, composition, etc)
- **id**: a unique identifier for the meteorite
- **nametype**: one of:
  - valid: a typical meteorite
  - relict: a meteorite that has been highly degraded by weather on Earth
- **recclass**: the class of the meteorite; one of a large number of classes based on physical, chemical, and other characteristics (see the Wikipedia article on meteorite classification

for a primer)
- **mass**: the mass of the meteorite, in grams
- **fall**: whether the meteorite was seen falling, or was discovered after its impact; one of:
  - Fell: the meteorite's fall was observed
  - Found: the meteorite's fall was not observed
- **year**: the year the meteorite fell, or the year it was found (depending on the value of fell)
- **reclat**: the latitude of the meteorite's landing
- **reclong**: the longitude of the meteorite's landing
- **GeoLocation**: a parentheses-enclose, comma-separated tuple that combines reclat and reclong

1.5 Ethical Considerations

The dataset owner is NASA Public Data and under the data.nasa.gov website, it is stated that the data is open-data provided to the public. [3]

According to NASA, under their Media Usage Guidelines,*"NASA content - images, audio, video, and computer files used in the rendition of 3-dimensional models, such as texture maps and polygon data in any format - generally are not subject to copyright in the United States. You may use this material for educational or informational purposes, including photo collections, textbooks, public exhibits, computer graphical simulations and Internet Web pages. This general permission extends to personal Web pages"*. [4]

This report does not violate NASA's policies in anyway. It it for personal and educational purposes only.

2 Visualizing the Meteorite Landings

In [1]:

```
import pandas as pd
import numpy as np
```

In [2]:

```
#load our csv file and create df

df = pd.read_csv("Meteorite_Landings.csv")
df.head(5)
```

Out[2]:

	name	id	nametype	recclass	mass (g)	fall	year	reclat	I
0	Aachen	1	Valid	L5	21.0	Fell	1880.0	50.77500	6
1	Aarhus	2	Valid	H6	720.0	Fell	1951.0	56.18333	1(
2	Abee	6	Valid	EH4	107000.0	Fell	1952.0	54.21667	-11:
3	Acapulco	10	Valid	Acapulcoite	1914.0	Fell	1976.0	16.88333	-9!
4	Achiras	370	Valid	L6	780.0	Fell	1902.0	-33.16667	-6

2.1 Time frame

Before we visualize the meteorite locations on Earth, it would be a good to know the time span in which these meteorites were found and how far back our data set dates to.

In [3]:

```
startYear = df['year'].min()
endYear = df['year'].max()
print(startYear,endYear)
```

```
860.0 2101.0
```

Interesting. The earliest recorded meteorite in the data set is the year 860, whether AD or BC, we will found out, and the latest seems to be the year 2101, which is puzzling since the current year as of this report is 2023. I can only assume that this could either be a prediction of a meteorite that will enter our atmosphere in the future, or that data is incorrect.

Lets explore the earliest meteorite first.

In [4]:

```
#get the row of meteorite landing in year 860
year860 = df.loc[df['year']==860.0]
year860
```

Out[4]:

	name	id	nametype	recclass	mass (g)	fall	year	reclat	reclong	G
704	Nogata	16988	Valid	L6	472.0	Fell	860.0	33.725	130.75	

2.2 Verifying the integrity of the earliest documented meteorite

In [5]:

```
#get the row of meteorite landing in year 860
year860 = df.loc[df['year']==860.0]
year860
```

Out[5]:

	name	id	nametype	recclass	mass (g)	fall	year	reclat	reclong	G
704	Nogata	16988	Valid	L6	472.0	Fell	860.0	33.725	130.75	

To check if such a meteorite exists, I keyed Nogata into Google and the first link led me to a Wikipedia article[5]. The article quotes:

> *The Nōgata meteorite is an L6 chondrite meteorite fragment, found in Fukuoka Prefecture, Japan. It is believed to be the oldest fragment associated with a sighting of a meteor fall. Witnessed by a young boy on May 19, 861, who led others to the impact site, it was accepted as having come from the sky. It was analyzed and described by Masako Shima of the National Science Museum of Tokyo and accepted by the Nomenclature Committee of the Meteoritical Society in 1979. Shima published a complete analysis of the chemical makeup of the fragment in 1983. It is on display in a Shinto shrine in Nōgata.*

The article mentions that the meteorite "Nōgata", was accepted by the Nomenclature Committee of the Meteoritical Society. I checked the "Nōgata" meteorite in the, The Meteoritical Society's database, and lo and behold, "Nōgata" exists, and its description matches that of ours in our data set, verifying its legitimacy.[6]

2.2 Verifying the integrity of the latest documented meteorite

In [6]:

```
#get the row of meteorite landing in year 2101
year2101 = df.loc[df['year']==2101.0]
year2101
```

Out[6]:

	name	id	nametype	recclass	mass (g)	fall	year	reclat	re(
30682	Northwest Africa 7701	57150	Valid	CK6	55.0	Found	2101.0	0.0	

As I suspected, there is indeed an error in this row of the data set. After back checking the data again using The Meteoritical Society's database, the year it was found was not in 2101, but 2010[7]. We will be dropping out this row in the data set as not only is the data entry wrong, but since the fall of the meteorite is labeled as "Found", meaning the fall was not observed, its location of impact is unknown.

In [7]:

```
#dropping the incorrect row and getting the next max year value
df = df.drop(30682)
latestYear = df['year'].max()
print(latestYear)

getrow_latestYear = df.loc[df['year']==2013.0]
getrow_latestYear
```

```
2013.0
```

Out[7]:

	name	id	nametype	recclass	mass (g)	fall	year	
194	Chelyabinsk	57165	Valid	LL5	100000.0	Fell	2013.0	54
30730	Northwest Africa 7755	57166	Valid	Martian (shergottite)	30.0	Found	2013.0	0
30762	Northwest Africa 7812	57258	Valid	Angrite	46.2	Found	2013.0	0
30763	Northwest Africa 7822	57268	Valid	Achondrite-ung	45.8	Found	2013.0	0
30774	Northwest Africa 7855	57420	Valid	H4	916.0	Found	2013.0	0
30775	Northwest Africa 7856	57421	Valid	LL6	517.0	Found	2013.0	0
30776	Northwest Africa 7857	57422	Valid	LL6	246.0	Found	2013.0	0
30777	Northwest Africa 7858	57423	Valid	H4	459.0	Found	2013.0	0
30779	Northwest Africa 7861	57425	Valid	L5	611.0	Found	2013.0	0
30780	Northwest Africa 7862	57426	Valid	L4/5	317.0	Found	2013.0	0
30781	Northwest Africa 7863	57427	Valid	LL5	1000.0	Found	2013.0	0

2.3 Removing empty, null and duplicate location entries

We now know our time frame. The recorded meteorite landings are from the year 861 to 2013 AD. However, there seems to be many entries that have no longitudinal and latitudinal locations, e.g "0.0" values under column "reclat" and "reclong", or empty cells.

It's highly unlikely that multiple meteorites land at exactly the same location multiple times. There are only two possible scenarios for this. One, the data is a duplicate or incorrect entry, or, that it is possible the recorded entries are from a meteor shower, where Earth passes through the path of a comet and small debris enter our atmosphere, which could explain why there are many entries in the data set that contain unique id's even though their geolocation is the same.

However, for the purpose of this report, we only want to see the unique geolocations of documented meteorites so that it is easy to visualize on a world map. Therefore, I will be dropping zero, empty and duplicate values from the dataset before plotting.

In [8]:

```
#remove rows that have 0.0 in reclat and reclong columns
df = df.drop(df[(df['reclat'] == 0) & (df['reclong'] == 0)].index)
len(df.index)
```

Out[8]:

```
39502
```

In [9]:

```
#remove duplicate entries
df.drop_duplicates('reclat', keep="first", inplace=True)
df.drop_duplicates('reclong', keep="first", inplace=True)
len(df.index)
```

Out[9]:

```
12037
```

Checker for any missing data

In [10]:

```
df.isna().sum(axis=0)
```

Out[10]:

```
name            0
id              0
nametype        0
recclass        0
mass (g)       45
fall            0
year          108
reclat          1
reclong         1
GeoLocation     1
dtype: int64
```

Check for the number of non-missing data against missing to see the scale or ratio of it

In [11]:

```
df.notna().sum(axis=0)
```

Out[11]:

```
name          12037
id            12037
nametype      12037
recclass      12037
mass (g)      11992
fall          12037
year          11929
reclat        12036
reclong       12036
GeoLocation   12036
dtype: int64
```

In [12]:

```
#ratio of missing value
ratio = 1/(12036+1) * 100
ratio
```

Out[12]:

```
0.008307717869901138
```

In [13]:

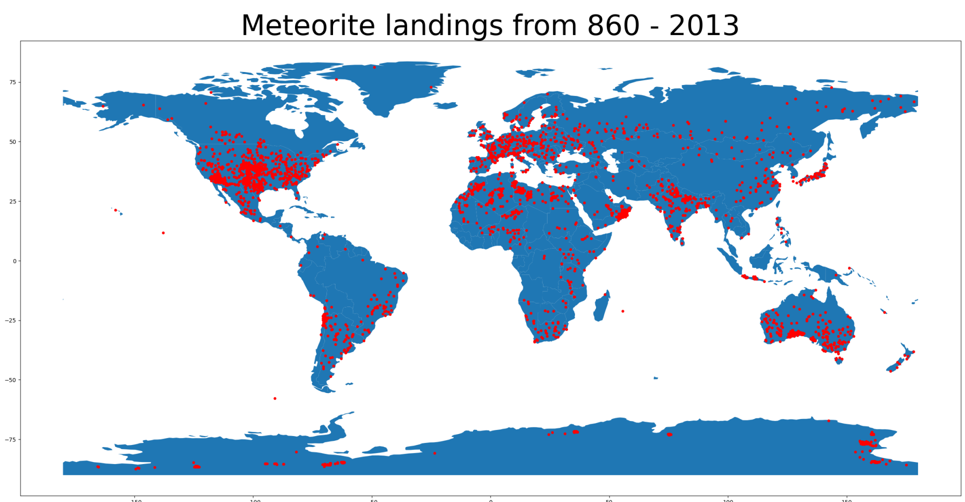
```
#drop the missing values for reclong and reclat
df = df.dropna()
```

In [14]:

```
#plot map vis
from shapely.geometry import Point
import geopandas as gpd
from geopandas import GeoDataFrame

geometry = [Point(xy) for xy in zip(df['reclong'], df['reclat'])]
gdf = GeoDataFrame(df, geometry=geometry)

world = gpd.read_file(gpd.datasets.get_path('naturalearth_lowres'))
axe = ax=world.plot(figsize=(30,30))
axe.set_title("Meteorite landings from 860 - 2013",fontsize = 50)
gdf.plot(ax=axe,marker='o', color='red', markersize=15);
```



2.4 Summary

After removing empty reclat and reclong entries, entries with 0.0 values, and duplicate values, we now have a visual display of a dot distribution map showing the unique geolocations of documented meteorites found on Earth from 861 to 2013.

I'm surprised that there are only 3 unique meteorite locations in Greenland, given the large land mass. But as expected North America seems to have the largest concentration of meteorite landings on Earth. Why?

3 Reasoning for density of documented meteorites in North America

- Population Density: North America has a higher population density than many other regions of the world, which means that there are more people to report and document meteorite sightings.
- Scientific Infrastructure: North America has a well-developed scientific infrastructure, with numerous universities, research institutions, and observatories that are equipped to study meteorites. This makes it more likely that meteorites will be identified, studied, and reported in this region.
- Geographical Size: North America is a large continent, covering over 9 million square miles. This means that it has a larger area for meteorites to potentially land on, increasing the likelihood of meteorite sightings and recoveries.

It is important to note that a large number of meteorites on Earth are retrieved from Antarctica. The reason Antarctica isn't heavily plotted in the dot distribution map above is that our data set only includes documented findings and sightings on meteorites in a given time frame that were admitted into The Meteoritical Society. Most meteorites are well-preserved in deserts, like Antarctica and the Sahara. However,these meteorites may date back millions of years ago, and may have shifted from their original landing location due to weather or shifting of land mass.

4 Material Composition of Meteorites

Meteorites originate from different parts of space, which means that the materials that make up these meteorites are bound to be different. Let's take a look at what the materials are.

In [15]:

```
import matplotlib.pyplot as plt
unique_mats = df['recclass'].unique()
unique_mats[:50]
```

Out[15]:

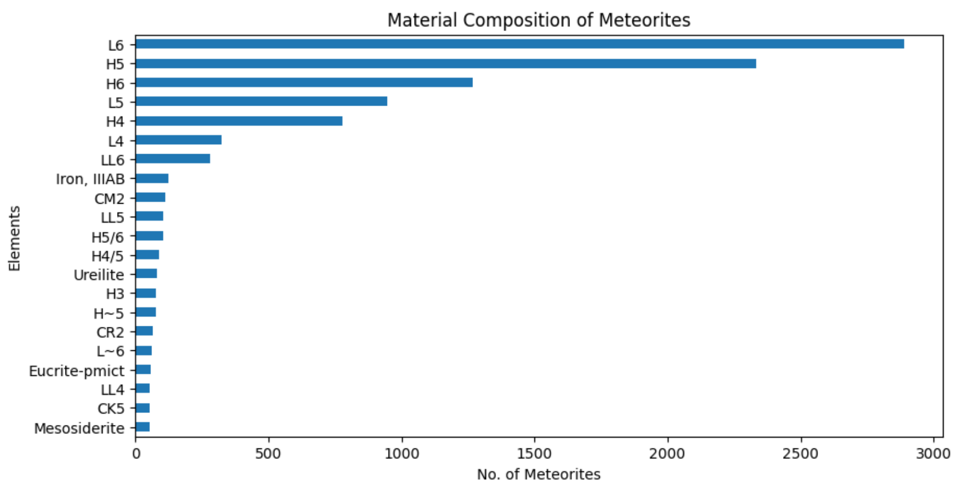
```
array(['L5', 'H6', 'EH4', 'Acapulcoite', 'L6', 'LL3-6', 'H5',
'L',
       'Diogenite-pm', 'H4', 'H', 'Iron, IVA', 'CR2-an', 'LL
5', 'CI1',
       'L/LL4', 'Eucrite-mmict', 'CV3', 'Ureilite-an', 'Stone-
uncl', 'L3',
       'Angrite', 'LL6', 'L4', 'Aubrite', 'Iron, IIAB', 'Iron,
IAB-sLL',
       'Iron, ungrouped', 'CM2', 'Mesosiderite-A1', 'LL4', 'C2
-ung',
       'LL3.8', 'Howardite', 'Eucrite-pmict', 'Diogenite', 'LL
3.15',
       'LL3.9', 'Iron, IAB-MG', 'Eucrite', 'H4-an', 'L/LL6',
'OC', 'H/L4',
       'H4-5', 'L3.7', 'LL3.4', 'Martian (chassignite)', 'Iro
n, IIIAB',
       'EL6'], dtype=object)
```

There are many meteorites with uncommon materials that have counts of only 1 in the data frame. We will not be displaying them as we only want to see what the vast majority of meteorites are made of.

4.1 Most common meteorite group

In [16]:

```
#sort and display unique elements that have more counts than 50
value_counts = df['recclass'].value_counts()
filter_ones = value_counts[value_counts > 50]
filter_ones = filter_ones.sort_values(ascending = True)
filter_ones.plot(figsize = [10,5],kind='barh',title = 'Material Composition c
plt.ylabel('Elements')
plt.xlabel('No. of Meteorites')
plt.show()
```



We can see the most common element found in these meteorite landings is classed as L6.

L6 is the L type ordinary chondrites. Ordinary chondites are a class of stony chondritic meteorites. According Wikipedia[8], chondrite can be defined as,

> *"a stony (non-metallic) meteorite that has not been modified, by either melting or differentiation of the parent body."*

L chondrites have a lower total iron and metal composition but higher iron oxide (Fa) in the silicates.

Unfortunately, the parent body that is associated with L6 meteorites are unknown, however plausible origins point to the "Flora Family", which is a family of asteroids located in the inner region of the asteroid belt of our solar system.

4.1 Discovery of new materials

Among these meteorites found, there is a possibility that scientist are able to discover new elements and materials from the rocks. And they have.

The most recent discovery of new materials originating from meteorites that are not found on Earth, was in 2020, when scientist discovered two new minerals from a meteorite nicknamed "Nightfall" in the district of El Ali, Somalia[9]. The official names for the discovered minerals are *"elaiite"* and *"elkinstantonite".*

An example of a material found in meteorites that is used in modern times, is iridium. One of the rarest materials on Earth that mainly resides in the core[10], majority of iridium deposits come from meteorites, aiding in the theory that a large asteroid impacted Earth millions of years ago, resulting in the extinction event of the dinosaurs. One of the uses of iridium is as a hardening agent for platinum.

Conclusion

In this exploratory data analysis, we have managed to uncover three things. One,we have visualized and seen where meteorites have landed on Earth from the year 860 to 2013 AD, and verified the integrity of the documented landings.

Two, we now have an understanding of what meteorite composition L6 is, which is what majority of meteorites found, are comprised of.

And finally, we have also verified that studying these fallen "space rocks" is necessary and we can discover new minerals that help fuel our modern infrastructure.

References

- [1]https://solarsystem.nasa.gov/resources/712/perseid-meteor-2016/?category=small-bodies_meteors-and-meteorites (https://solarsystem.nasa.gov/resources/712/perseid-meteor-2016/?category=small-bodies_meteors-and-meteorites)
- [2] https://data.nasa.gov/Space-Science/Meteorite-Landings/gh4g-9sfh (https://data.nasa.gov/Space-Science/Meteorite-Landings/gh4g-9sfh)
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