Radon Distribution in Northern Ireland - A Geological Perspective

This program has threefold

List of libraries/packages used in this notebook

pandas: data analysis and manipulation tool. Info: https://pandas.pydata.org/ (https://pandas.pydata.org/)

geopandas: enable working with geospatial data, allows spatial operations on geometric types. Info: https://geopandas.org/ (https://geopandas.org/)

geoplot: a geospatial plotting library. Source: https://residentmario.github.io/geoplot/index.html (https://residentmario.github.io/geoplot/index.html)

shapely: for manipulation and analysis of planar geometric objects. Info: https://pypi.org/project/Shapely/ (https://pypi.org/project/Shapely/)

matplotlib: for creating static, animated, and interactive visualizations in Info. https://matplotlib.org/ (https://matplotlib.org/)

cartopy: for drawing maps for data analysis and visualisation. Info: https://pypi.org/project/Cartopy/ (https://pypi.org/project/Cartopy/)

contextily: to retrieve tile maps or basemaps from the internet. Info: https://contextily.readthedocs.io/en/latest/ (https://contextily.readthedocs.io/en/latest/)

seaborn: for drawing attractive and informative statistical graphics, based on matplotlib. Info: https://seaborn.pydata.org/ (https://seaborn.pydata.org/)

rasterio: provides access to geospatial raster data such as GeoTIFFs. Info: https://rasterio.readthedocs.io/en/latest/ (https://rasterio.readthedocs.io/en/latest/)

pydoc: documentation generator and online help system https://docs.python.org/3/library/pydoc.html (https://docs.python.org/3/library/pydoc.html)

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1. Import the required libraries

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The use of **%matplotlib notebook** below makes the plots interactive

In [1]:
```
%matplotlib notebook

import pandas as pd
import geopandas as gpd
import geoplot as gplt
from shapely.geometry import Point, LineString, Polygon
import matplotlib.pyplot as plt
import matplotlib.patches as mpatches
import matplotlib.lines as mlines
from matplotlib_scalebar.scalebar import ScaleBar
import cartopy as cp
from cartopy import config
from cartopy.feature import ShapelyFeature
import cartopy.crs as ccrs
import contextily as ctx
import seaborn as sns
import rasterio as rio
import pydoc
```

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2. Define figure formats and make plotting interactive

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In [2]:
```
plt.rcParams.update({'font.size': 8}) # adjust the font size for the plots to be size 8


plt.ion() # make the plotting interactive

# generate matplotlib handles to create a legend of the features we put in our map.
def generate_handles(labels, colors, edge='k', alpha=1):
    lc = len(colors)  # get the length of the color list
    handles = []
    for i in range(len(labels)):
        handles.append(mpatches.Rectangle((0, 0), 1, 1, facecolor=colors[i % lc], edgecolor=edge, alpha=alpha))
    return handles

# create a scale bar of length 20 km in the upper right corner of the map
# adapted this question: https://stackoverflow.com/q/32333870, answered by SO user Siyh: https://stackoverflow.com/a/357

def scale_bar(ax, location=(0.92, 0.95)):
    llx0, llx1, lly0, lly1 = ax.get_extent(ccrs.PlateCarree())
    sbllx = (llx1 + llx0) / 2
    sblly = lly0 + (lly1 - lly0) * location[1]

    tmc = ccrs.TransverseMercator(sbllx, sblly)
    x0, x1, y0, y1 = ax.get_extent(tmc)
    sbx = x0 + (x1 - x0) * location[0]
    sby = y0 + (y1 - y0) * location[1]

    plt.plot([sbx, sbx - 20000], [sby, sby], color='k', linewidth=9, transform=tmc)
    plt.plot([sbx, sbx - 10000], [sby, sby], color='k', linewidth=6, transform=tmc)
    plt.plot([sbx-10000, sbx - 20000], [sby, sby], color='w', linewidth=6, transform=tmc)

    plt.text(sbx, sby-4500, '20 km', transform=tmc, fontsize=10)
    plt.text(sbx-12500, sby-4500, '10 km', transform=tmc, fontsize=10)
    plt.text(sbx-24500, sby-4500, '0 km', transform=tmc, fontsize=10)
```

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3. Read the datafiles

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In [3]:
```
#Read radon data of the Northern Ireland
radon_table = pd.read_csv('data_files\RadonNI.csv')

""" read csv file """
# load the Counties shapefile
counties_orig = gpd.read_file('data_files/Counties.shp')

""" read shapefile """

# load the bedrock geology layer of Northern Ireland
bedrocks = gpd.read_file('data_files/NIbedrocks.shp')
```

==

4. RADON data

==

In [4]:
```
radon_table.shape # dispaly the data structure: 14720 rows and 4 columns
```

Out[4]:
```
(14720, 4)
```

In [5]:
```
radon_table.info() # More information about the data: 14720 entries, position from 0 to 14719, arranged in 4 columns
                    # first column is object format, while the other three columns are in integer formats
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 14720 entries, 0 to 14719
Data columns (total 4 columns):
 #   Column  Non-Null Count  Dtype 
---  ------  --------------  ----- 
 0   Tile    14720 non-null  object
 1   class   14720 non-null  int64 
 2   x       14720 non-null  int64 
 3   y       14720 non-null  int64 
dtypes: int64(3), object(1)
memory usage: 460.1+ KB
```

In [6]:
```
radon_table.head(10) #show the top 10 rows with the column headings
```

Out[6]:

	Tile	class	x	y
0	D1053	1	310500	453500
1	D1153	1	311500	453500
2	D1253	1	312500	453500
3	D0952	2	309500	452500
4	D1052	2	310500	452500
5	D1152	2	311500	452500
6	D1252	2	312500	452500
7	D1352	2	313500	452500
8	D1452	2	314500	452500
9	D1552	1	315500	452500

In [7]:
```
# summary statistics of all the data
radon_table.describe()
```

Out[7]:

	class	x	y
count	14720.000000	14720.000000	14720.000000
mean	2.682541	284638.111413	373938.383152
std	1.541938	41306.305800	32692.536830
min	1.000000	188500.000000	309500.000000
25%	1.000000	250500.000000	347500.000000
50%	2.000000	288500.000000	370500.000000
75%	4.000000	318500.000000	399500.000000
max	6.000000	366500.000000	453500.000000

In [8]:
```
radon_table["class"].describe() # Summary statistics of the radon data only. Radon classes ranges from 1 to 6.
```

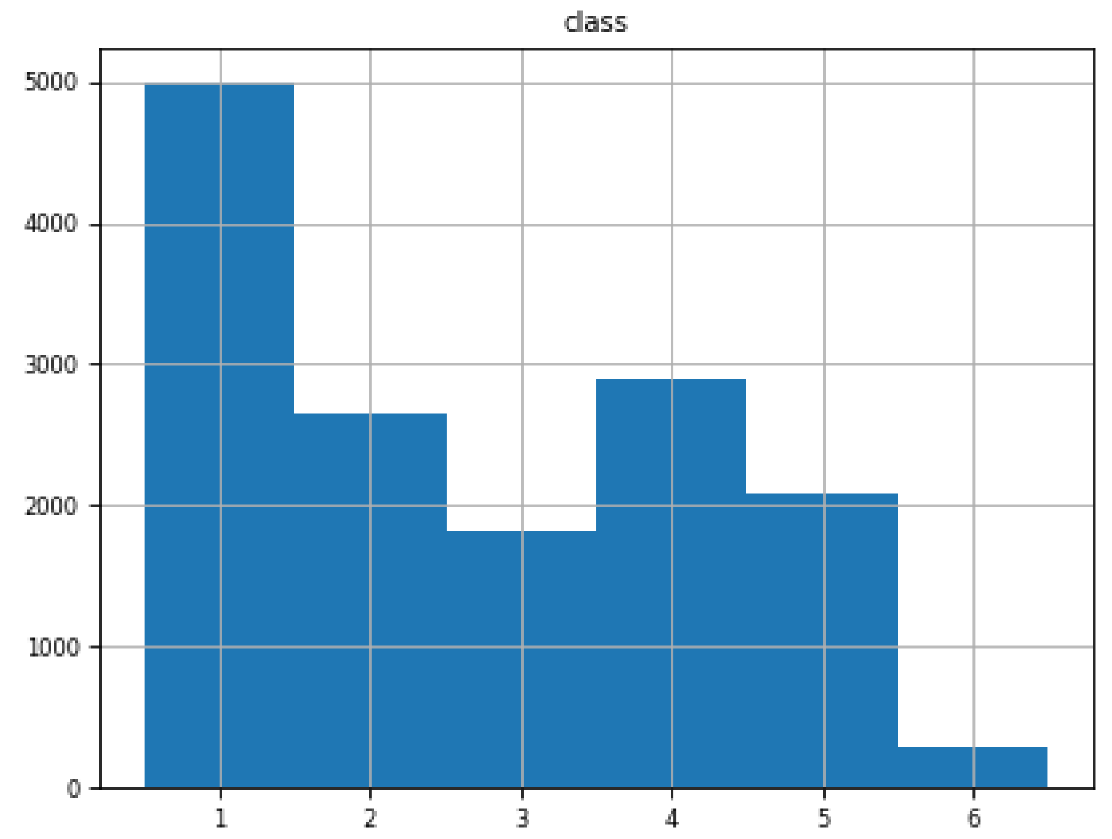
Out[8]:
```
count    14720.000000
mean         2.682541
std          1.541938
min          1.000000
25%          1.000000
50%          2.000000
75%          4.000000
max          6.000000
Name: class, dtype: float64
```

In [9]:
```
radon_table['class'].describe().round(0) # descriptive statistics of the radon classes, round numbers to nearest integer
```

Out[9]:
```
count    14720.0
mean         3.0
std          2.0
min          1.0
25%          1.0
50%          2.0
75%          4.0
max          6.0
Name: class, dtype: float64
```

In [10]:
```
radon_table.hist(column='class', bins=[0.5,1.5,2.5,3.5,4.5,5.5,6.5]); # Histogram plot of the radon classes.
                                                                      # Class 1 is very common, followed by class 4.
                                                                      # Class 6 is rare.
```

Figure 1



Radon Potential Classes and percentage bands

| Radon Potential Class | Nominal percentage band |

| 1 | 0-1 |

| 2 | 1-3 |

| 3 | 3-5 |

| 4 | 5-10 |

| 5 | 10-30 |

| 6 | 30-100 |

Nominal percentage band = Estimated percentage of dwellings exceeding the Radon Action Level

The **UK radon 'Action Level'** is 200 becquerels per cubic metre for the annual average of the radon gas concentration in a home. Radon classes above describe whether a property is in a radon Affected Area and the percentage of homes that are estimated to be at or above the radon Action Level.

In conclusion, The higher the radon class, the higher risk of radon exposure. Class 1 indicates that 0 - 1 % of dwellings, in a specific area, are at risk of radon exposure higher than the UK normal radon level.

The radon data provides an estimation, actual radon emission requires a radon measurement in an existing property

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5. Geospatial Analysis of the RADON data

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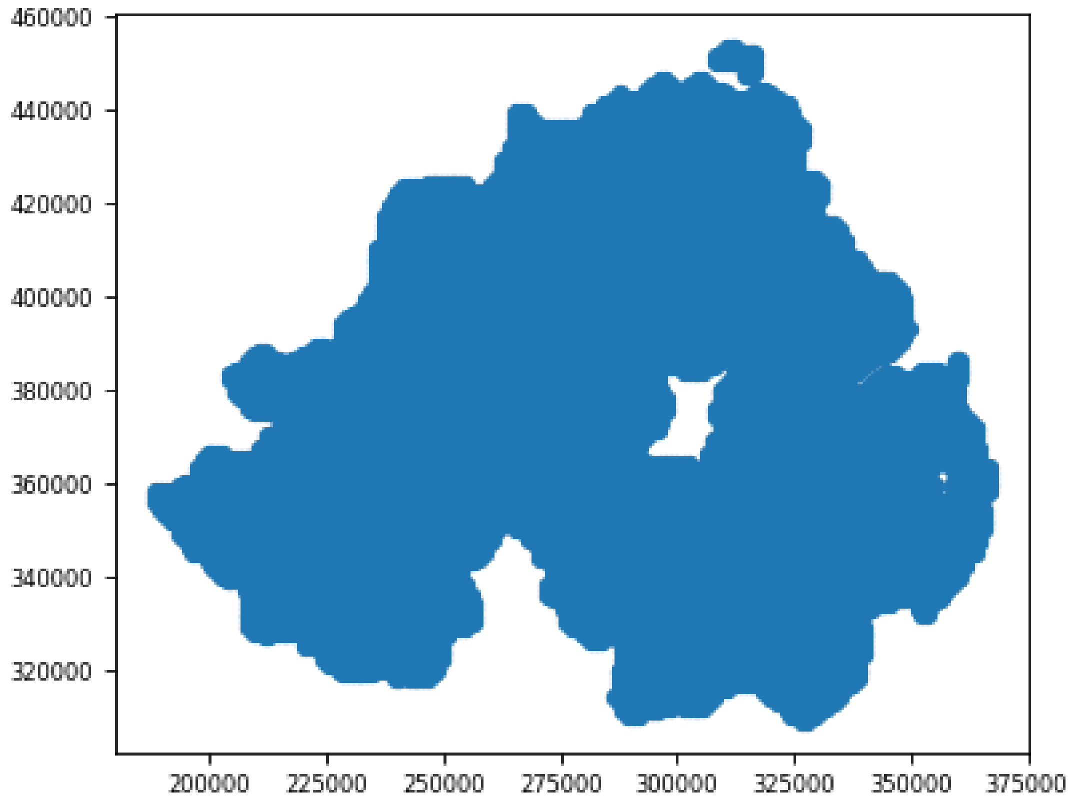
In [11]:
```
# set the coordinate type (to epsg:29902; i.e. TM65 / Irish Grid) and plot the radon data with respect to x, y
pts = [Point(row['x'], row['y']) for id, row in radon_table[['x', 'y']].iterrows()]

""" Assign the xy coordinates from the radon data """

pts = gpd.GeoSeries(pts, crs='+init=epsg:29902')

# plot the radon data with respect to their coordinates
pts.plot();
```

```
C:\Users\asuwa\anaconda3\envs\RadonNI\lib\site-packages\pyproj\crs\crs.py:280: FutureWarning: '+init=<authority>:<code
>' syntax is deprecated. '<authority>:<code>' is the preferred initialization method. When making the change, be mindfu
l of axis order changes: https://pyproj4.github.io/pyproj/stable/gotchas.html#axis-order-changes-in-proj-6 (https://pyp
roj4.github.io/pyproj/stable/gotchas.html#axis-order-changes-in-proj-6)
  projstring = _prepare_from_string(projparams)
```

Figure 2



x=2.588e+05 y=3.291e+05

In [12]:
```
pts.crs # check the coordinate systems, i.e. check if the previous code worked!
```

Out[12]:
```
<Projected CRS: EPSG:29902>
Name: TM65 / Irish Grid
Axis Info [cartesian]:
- E[east]: Easting (metre)
- N[north]: Northing (metre)
Area of Use:
- name: Ireland - onshore.
- bounds: (-10.56, 51.39, -5.93, 55.43)
Coordinate Operation:
- name: Irish Grid
- method: Transverse Mercator
Datum: TM65
- Ellipsoid: Airy Modified 1849
- Prime Meridian: Greenwich
```

In [13]:
```
# another way to assign the coordinate system (perhaps more simple)
radon_gdf = gpd.GeoDataFrame(radon_table, geometry=gpd.points_from_xy(radon_table.x, radon_table.y), crs='+init=epsg:299
```

```
C:\Users\asuwa\anaconda3\envs\RadonNI\lib\site-packages\pyproj\crs\crs.py:280: FutureWarning: '+init=<authority>:<code
>' syntax is deprecated. '<authority>:<code>' is the preferred initialization method. When making the change, be mindfu
l of axis order changes: https://pyproj4.github.io/pyproj/stable/gotchas.html#axis-order-changes-in-proj-6 (https://pyp
roj4.github.io/pyproj/stable/gotchas.html#axis-order-changes-in-proj-6)
  projstring = _prepare_from_string(projparams)
```

In [14]:
```
radon_gdf.crs # check the coordinate system of the new dataset (radon_gdf)
```

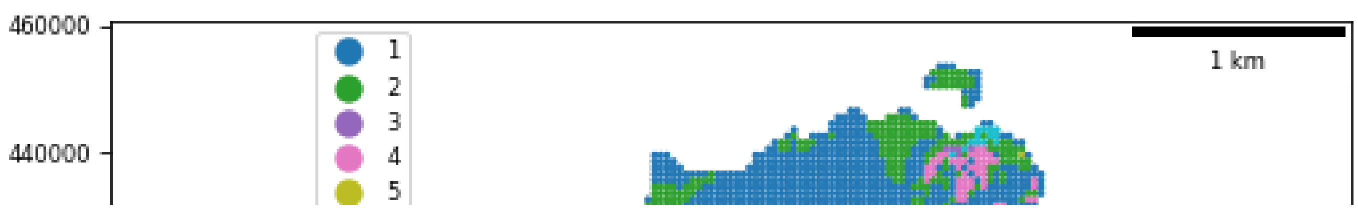
Out[14]:
```
<Projected CRS: EPSG:29902>
Name: TM65 / Irish Grid
Axis Info [cartesian]:
- E[east]: Easting (metre)
- N[north]: Northing (metre)
Area of Use:
- name: Ireland - onshore.
- bounds: (-10.56, 51.39, -5.93, 55.43)
Coordinate Operation:
- name: Irish Grid
- method: Transverse Mercator
Datum: TM65
- Ellipsoid: Airy Modified 1849
- Prime Meridian: Greenwich
```

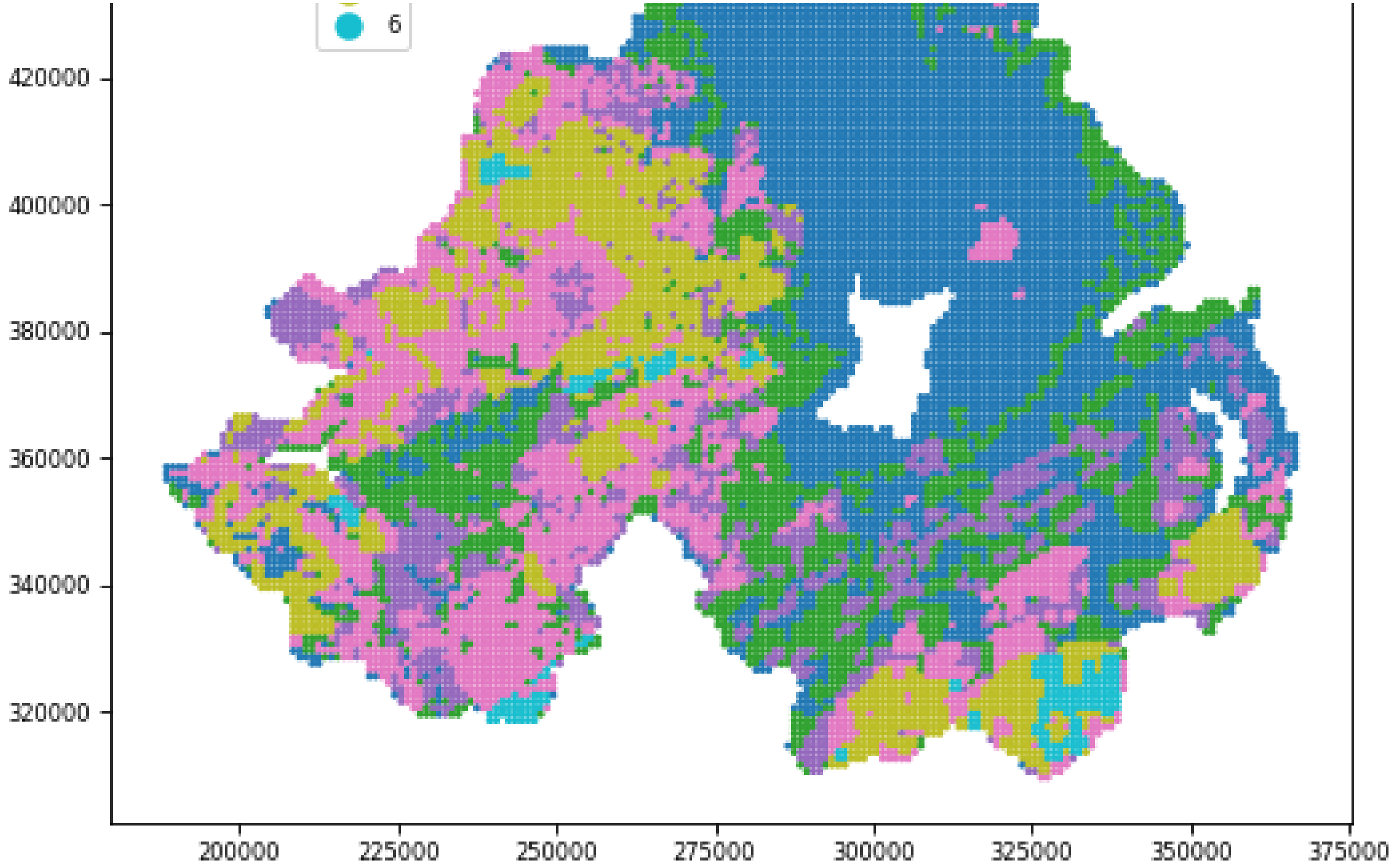
In [15]:
```
radon_gdf.to_file('data_files/RadonNI.shp') # create a new shapefile of the radon data
```

In [16]:
```
radon = gpd.read_file('data_files/RadonNI.shp') # load the radon shapefile
```

In [17]:
```python
# Display the radon distribution, symbology is based on the "class" attribute/column.
fig, ax = plt.subplots(figsize=(8, 8))

""" Design the plot """

radon.plot(column='class',
                categorical=True,
                legend=True,
                ax=ax,
                  markersize=3)

""" identify the column to plot and add legend """

# Adjust legend location
leg = ax.get_legend()
leg.set_bbox_to_anchor((0.25,1))

# Add map frames/axes
ax.set_axis_on()

scalebar = ScaleBar(3, "cm", length_fraction=0.25)
ax.add_artist(scalebar)

plt.show()
```

Figure 3





Left button pans, Right button zooms x/y fixes axis, CTRL fixes aspect

Note the class distribution above. Class 1 is dominant, especially in the nothern and eastern parts of Northern Ireland, while class 4 is very common in the western parts. Cluster distribution is mostly patchy. In the southeastern area, the classes seems to follow a linear pattern with a general NE - SW drection.

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6. Radon potential level in various counties

==

In [18]:
```
counties_orig.shape # Table of attributes of the "counties" shapefile is made up of 6 rows (6 counties) and five columns
```
Out[18]:
```
(6, 5)
```

In [19]:
```
counties_orig.columns # read the column headings
```
Out[19]:
```
Index(['COUNTY_ID', 'CountyName', 'Area_SqKM', 'OBJECTID', 'geometry'], dtype='object')
```

In [20]:
```
divisions = counties_orig['CountyName'].tolist() # Get a list of a the counties; 6 counties
print(divisions)
```
```
['TYRONE', 'ANTRIM', 'ARMAGH', 'FERMANAGH', 'LONDONDERRY', 'DOWN']
```

In [21]:
```
# display the data.

counties_orig.head()
```
Out[21]:

	COUNTY_ID	CountyName	Area_SqKM	OBJECTID	geometry
0	6	TYRONE	3265.796622	1	POLYGON ((-7.38177 54.94208, -7.38170 54.94201...
1	1	ANTRIM	3097.847750	2	MULTIPOLYGON (((-5.95296 54.55222, -5.95298 54...
2	2	ARMAGH	1327.228438	3	POLYGON ((-6.35398 54.50927, -6.35191 54.50891...
3	4	FERMANAGH	1850.832538	4	POLYGON ((-7.69417 54.60511, -7.69390 54.60498...
4	5	LONDONDERRY	2118.316853	5	POLYGON ((-6.66919 55.19899, -6.66918 55.19893...

Note that each county is represented by one polygon while county Antrim is represnted by more than one polygon (multipolygon)

County Antrim occupies part of the mainland and the Rathlin iseland in the north, hence is presented by two polygons

In [22]:
```python
# sort the counties according to their area (in km2), starting with the largest.
counties_orig.groupby("CountyName").mean().sort_values(by = "Area_SqKM", ascending = False)
```

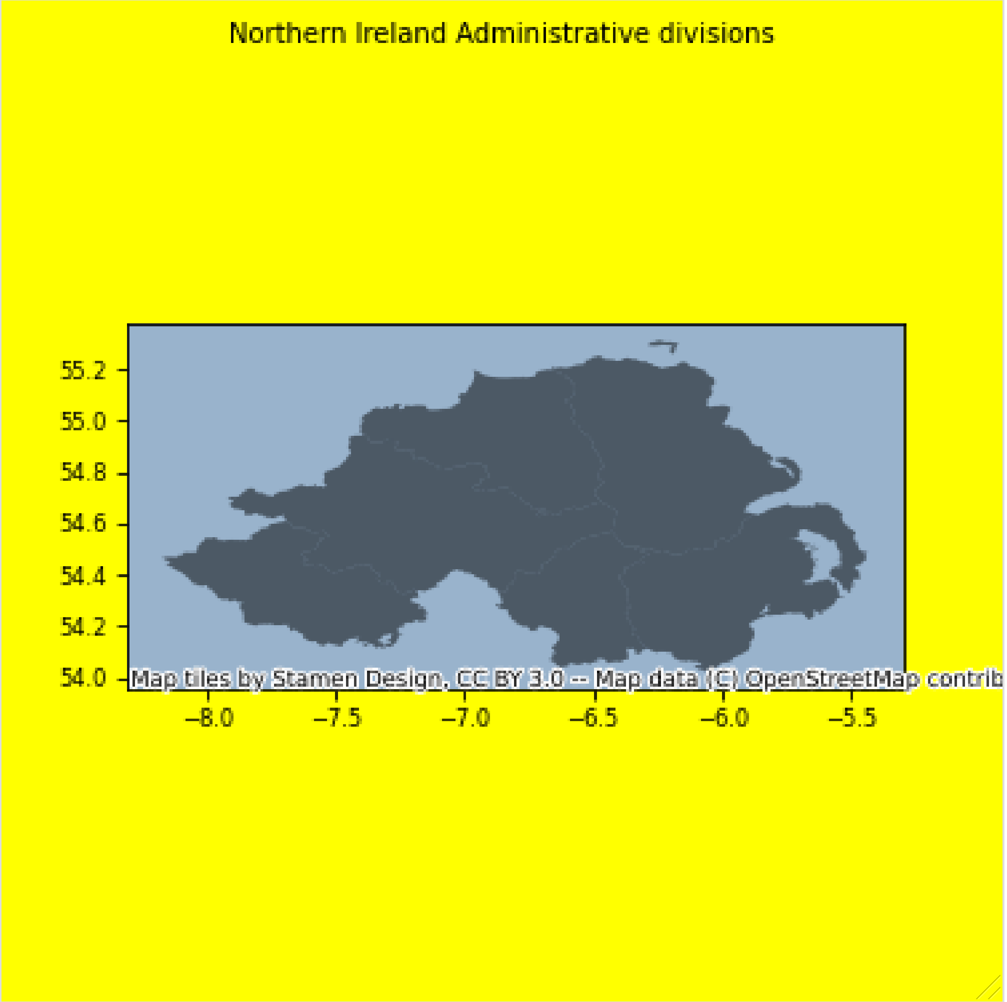
Out[22]:

CountyName	COUNTY_ID	Area_SqKM	OBJECTID
TYRONE	6	3265.796622	1
ANTRIM	1	3097.847750	2
DOWN	3	2491.238606	6
LONDONDERRY	5	2118.316853	5
FERMANAGH	4	1850.832538	4
ARMAGH	2	1327.228438	3

Note that County Tyrone is the largest in area.

In [23]:
```
# to show a basemap background
f, ax = plt.subplots(1, figsize=(5, 5), edgecolor="blue", facecolor="yellow")
counties_orig.plot(color='k', alpha=0.5, ax=ax)
ctx.add_basemap(ax)
plt.show('CountyName')
f.suptitle('Northern Ireland Administrative divisions')
plt.show()
```

Figure 4



x=−7.17 y=53.97 [153, 179, 204, 255]

```
C:\Users\asuwa\anaconda3\envs\RadonNI\lib\site-packages\contextily\tile.py:632: UserWarning: The inferred zoom level of
26 is not valid for the current tile provider (valid zooms: 0 - 18).
  warnings.warn(msg)
```

In [24]:
```
counties_orig.crs # check the coordinate system of the counties shapefile, it is EPSG:4326
```

Out[24]:
```
<Geographic 2D CRS: EPSG:4326>
Name: WGS 84
Axis Info [ellipsoidal]:
- Lat[north]: Geodetic latitude (degree)
- Lon[east]: Geodetic longitude (degree)
Area of Use:
- name: World.
- bounds: (-180.0, -90.0, 180.0, 90.0)
Datum: World Geodetic System 1984
- Ellipsoid: WGS 84
- Prime Meridian: Greenwich
```

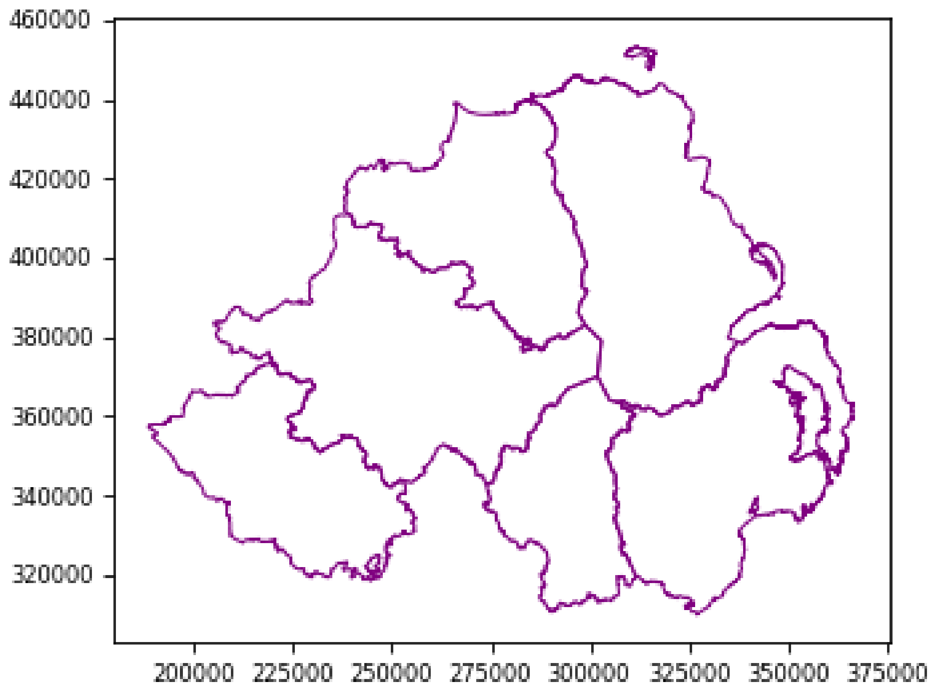
In [25]:
```
counties = counties_orig.to_crs(epsg=29902) # change the CRS to epsg=29902, to match the radon data coordinates
```

In [26]:
```
# check the coordinates again
counties.crs
```

Out[26]:
```
<Projected CRS: EPSG:29902>
Name: TM65 / Irish Grid
Axis Info [cartesian]:
- E[east]: Easting (metre)
- N[north]: Northing (metre)
Area of Use:
- name: Ireland - onshore.
- bounds: (-10.56, 51.39, -5.93, 55.43)
Coordinate Operation:
- name: Irish Grid
- method: Transverse Mercator
Datum: TM65
- Ellipsoid: Airy Modified 1849
- Prime Meridian: Greenwich
```

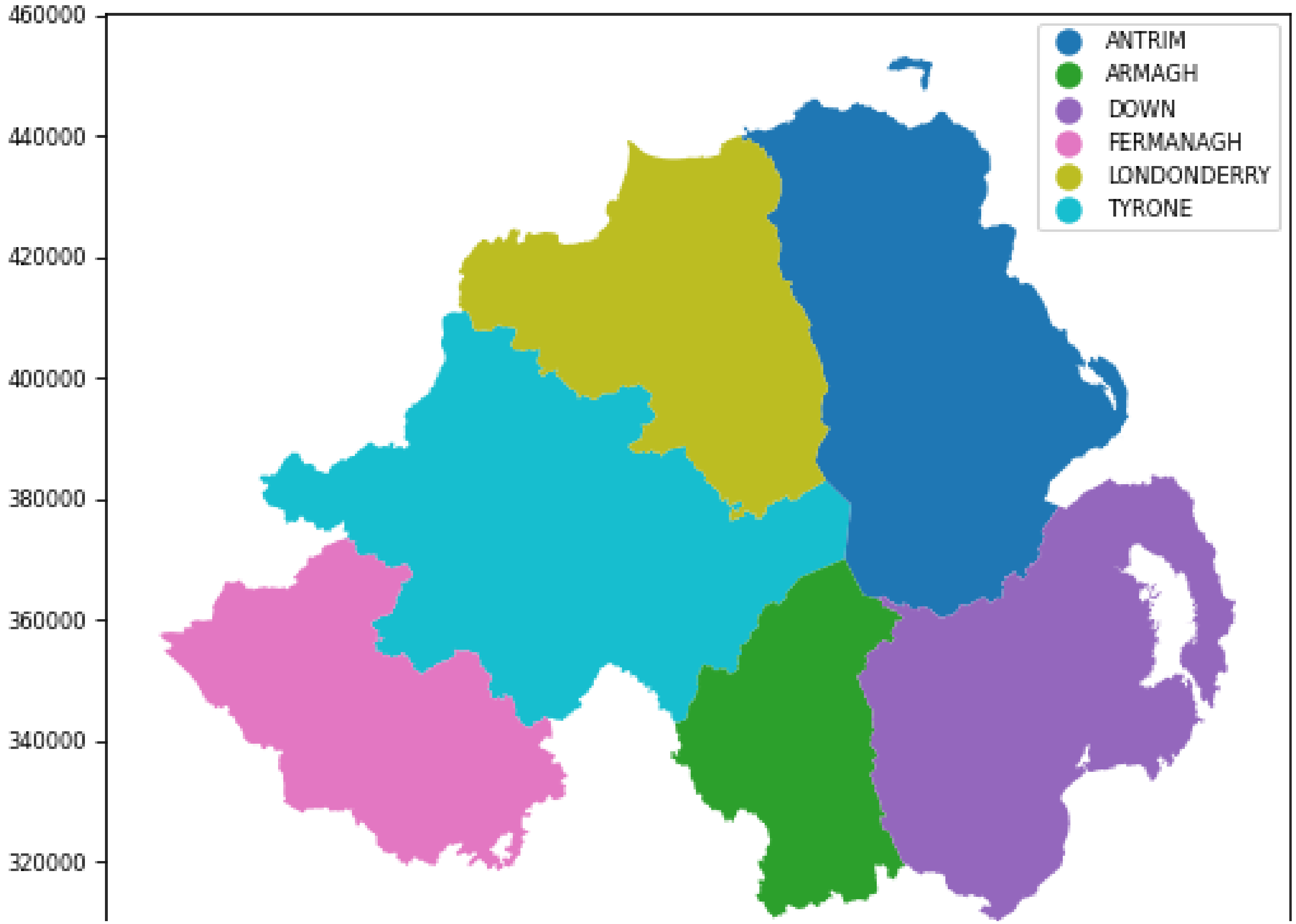
In [27]:
```
# Plot the counties again. Note the difference in  shape of the polygons and the coordinates numbers compared to code 23
# Note here that we used "edgecolor" and "facecolor" to manipulate the appearance of the polygons
counties.plot(figsize=(5,5), edgecolor="purple", facecolor="None"); # plot the counties in the Northern Ireland
```

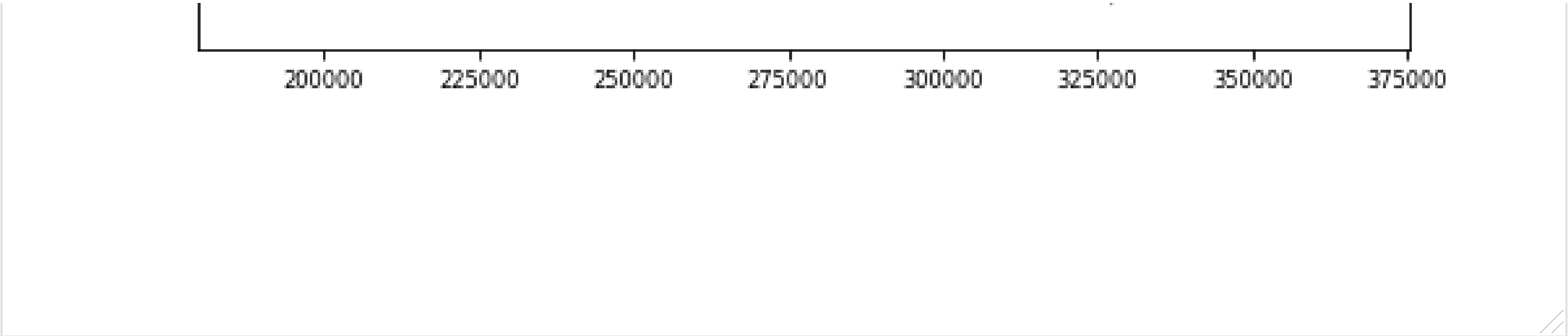
Figure 5



In [28]:
```python
# Plot the counties, symbology follows the county name (attribute "CountyName")
counties.plot('CountyName', legend=True, figsize=(8, 8));
```

Figure 6





Zoom to rectangle x/y fixes axis, CTRL fixes aspect

In [29]:
```
print(radon.crs == counties.crs) # check if the CRS of the radon and counties data are the same
```

```
True
```

In [30]:
```
#join (spatial join) the radon and counties data
radon_counties = gpd.sjoin(counties, radon, how='inner', lsuffix='left', rsuffix='right')  # join the two datasets into
```

In [31]:
```
radon_counties # display the new dataset, point datasets combining the radon and the county where each point is located
```

Out[31]:

	COUNTY_ID	CountyName	Area_SqKM	OBJECTID	geometry	index_right	Tile	class	x	y
0	6	TYRONE	3265.796622	1	POLYGON ((239669.128 410673.862, 239674.096 41...	11267	H7546	4	275500	346500
0	6	TYRONE	3265.796622	1	POLYGON ((239669.128 410673.862, 239674.096 41...	11268	H7646	3	276500	346500
0	6	TYRONE	3265.796622	1	POLYGON ((239669.128 410673.862, 239674.096 41...	11109	H7647	2	276500	347500
0	6	TYRONE	3265.796622	1	POLYGON ((239669.128 410673.862, 239674.096 41...	11723	H7343	3	273500	343500
0	6	TYRONE	3265.796622	1	POLYGON ((239669.128 410673.862, 239674.096 41...	11724	H7443	3	274500	343500
...	...	...	...	...	...	...	...	...	...	...
5	3	DOWN	2491.238606	6	MULTIPOLYGON (((325844.568 312608.674, 325840....	8630	J2662	1	326500	362500
5	3	DOWN	2491.238606	6	MULTIPOLYGON (((325844.568 312608.674, 325840....	8631	J2762	1	327500	362500
5	3	DOWN	2491.238606	6	MULTIPOLYGON (((325844.568 312608.674, 325840....	8612	J0862	3	308500	362500
5	3	DOWN	2491.238606	6	MULTIPOLYGON (((325844.568 312608.674, 325840....	8445	J0863	1	308500	363500
5	3	DOWN	2491.238606	6	MULTIPOLYGON (((325844.568 312608.674, 325840....	8444	J0763	1	307500	363500

13855 rows × 10 columns

In [32]:
```
radon_counties.shape # structure of the new dataset; 13855 rows and 10 columns
```

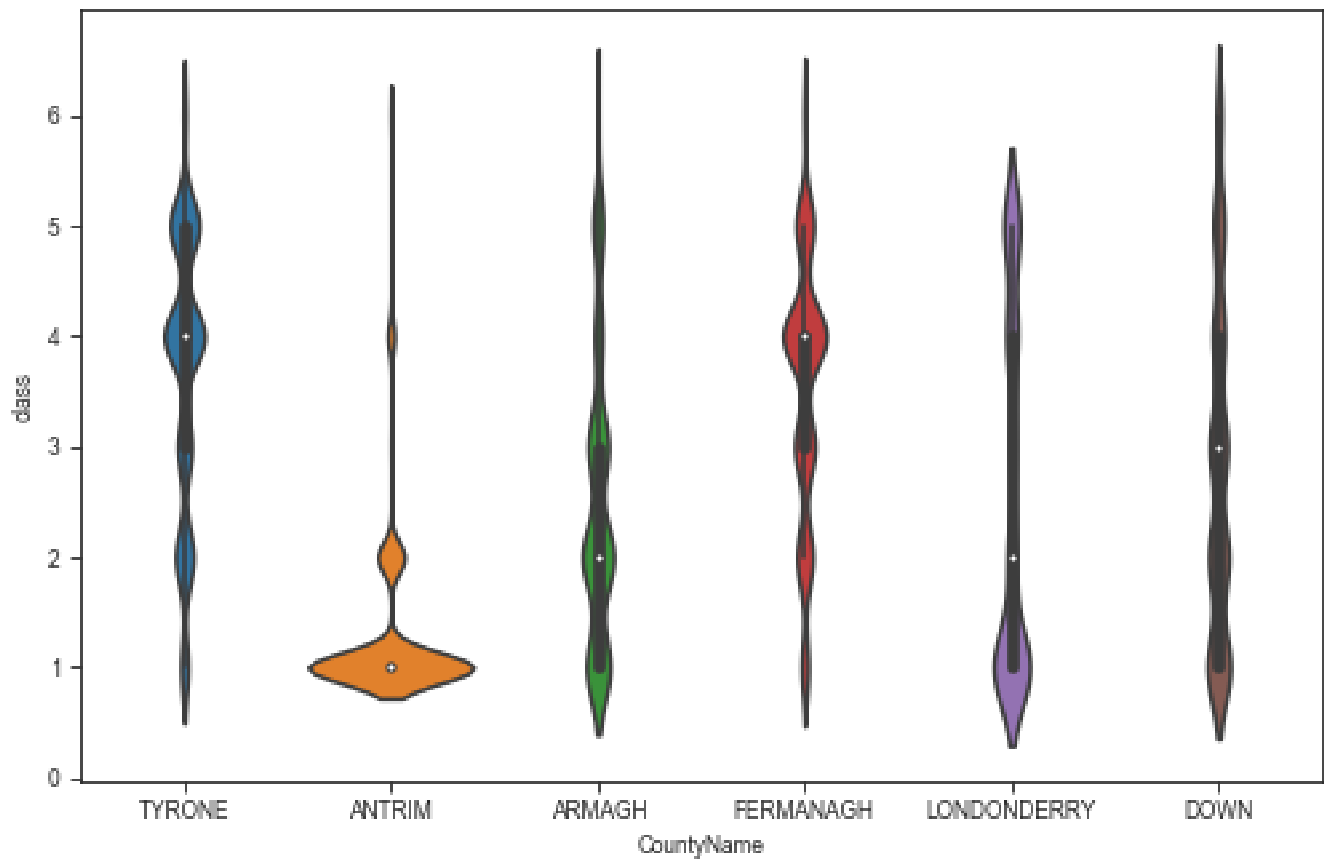
Out[32]:
```
(13855, 10)
```

In [33]:
```
radon_counties.info() #type of data within the new dataset
```

```
<class 'geopandas.geodataframe.GeoDataFrame'>
Int64Index: 13855 entries, 0 to 5
Data columns (total 10 columns):
 #   Column       Non-Null Count  Dtype
---  ------       --------------  -----
 0   COUNTY_ID    13855 non-null  int64
 1   CountyName   13855 non-null  object
 2   Area_SqKM    13855 non-null  float64
 3   OBJECTID     13855 non-null  int64
 4   geometry     13855 non-null  geometry
 5   index_right  13855 non-null  int64
 6   Tile         13855 non-null  object
 7   class        13855 non-null  int64
 8   x            13855 non-null  int64
 9   y            13855 non-null  int64
dtypes: float64(1), geometry(1), int64(6), object(2)
memory usage: 1.2+ MB
```

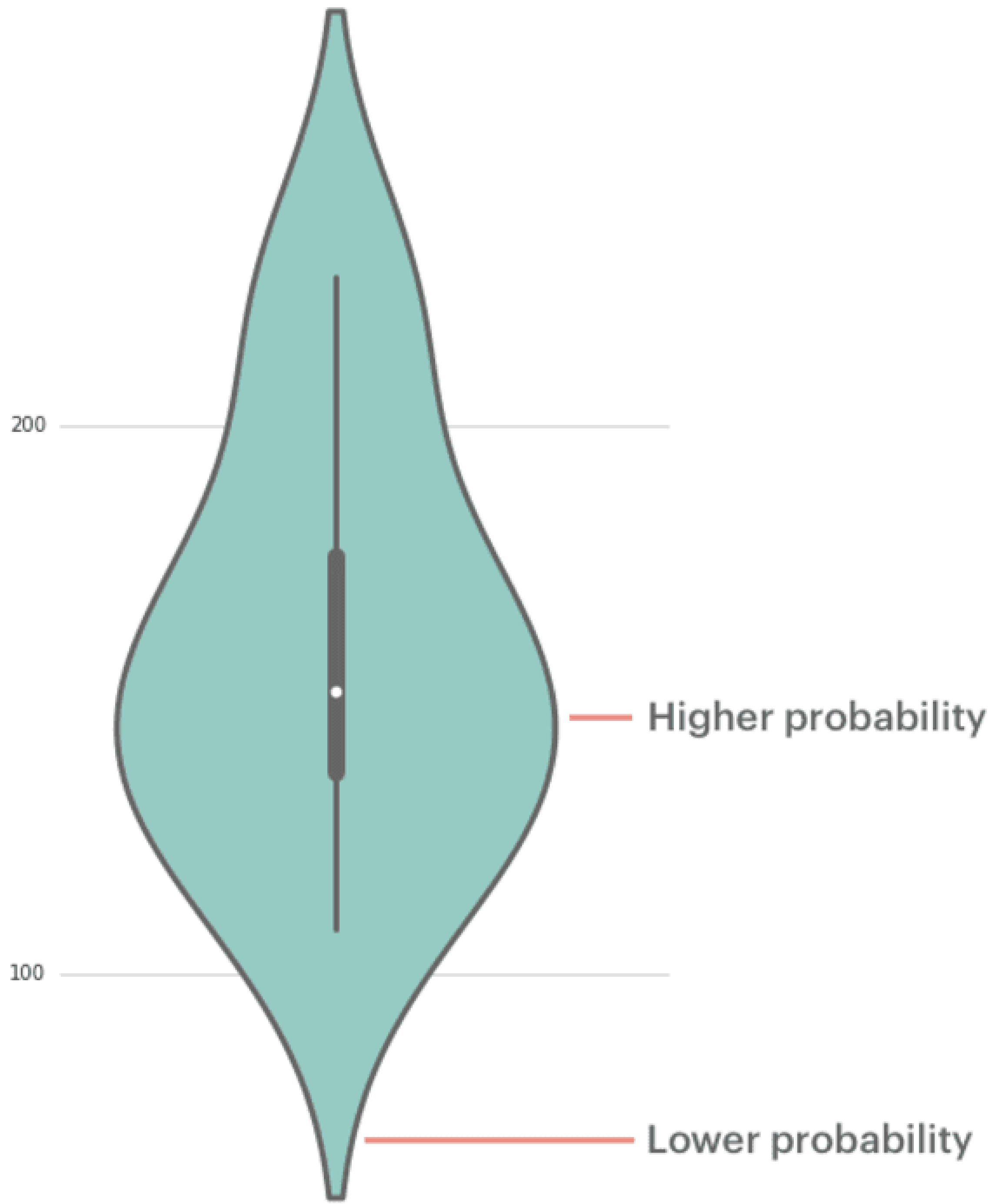
In [34]:
```
# Distribution of various classes within the counties.
# Each county contian the 6 radon classess, except County LONDONDERRY where class 6 is absent.
# Note that we are using Seaborn package
# code is adapted from: https://stackoverflow.com/questions/31594549/how-do-i-change-the-figure-size-for-a-seaborn-plot

sns.set_style('ticks')
fig, ax = plt.subplots()

# set the size of the graph
fig.set_size_inches(8, 5)
sns.violinplot(x = "CountyName", y = "class", data = radon_counties)

"""plotting numeric data, with the addition of a rotated kernel density plot on each side """

#save the figure as an image
fig.savefig('data files/Radon classes Counties.png')
```

Figure 7



Some notes to help you understanding the Violin plot (source: [https://mode.com/blog/violin-plot-examples/ (https://mode.com/blog/violin-plot-examples/)](https://mode.com/blog/violin-plot-examples/))

Violin plots are quite similar to box plots. The white dots above represents the median while the thick grey bar in the centers represent the interquartile range. The thin gray line represents the rest of the distribution. Wider sections of the violin plot represent a higher probability that members of the population will take on the given value; the skinnier sections represent a lower probability. At County Tyrone, the median of radon potetial level lies around class 4 and considered the highest among the counties.


200
100
Higher probability
Lower probability

In [35]:
```
# assign the CRS to the new dataset (joined radon - counties dataset)

radon_counties_gdf = gpd.GeoDataFrame(radon_counties, geometry=gpd.points_from_xy(radon_counties.x, radon_counties.y), cr
```

```
C:\Users\asuwa\anaconda3\envs\RadonNI\lib\site-packages\pyproj\crs\crs.py:280: FutureWarning: '+init=<authority>:<code
>' syntax is deprecated. '<authority>:<code>' is the preferred initialization method. When making the change, be mindfu
l of axis order changes: https://pyproj4.github.io/pyproj/stable/gotchas.html#axis-order-changes-in-proj-6 (https://pyp
roj4.github.io/pyproj/stable/gotchas.html#axis-order-changes-in-proj-6)
  projstring = _prepare_from_string(projparams)
```

In [36]:
```
radon_counties_gdf.crs # check the CRS
```

Out[36]:
```
<Projected CRS: EPSG:29902>
Name: TM65 / Irish Grid
Axis Info [cartesian]:
- E[east]: Easting (metre)
- N[north]: Northing (metre)
Area of Use:
- name: Ireland - onshore.
- bounds: (-10.56, 51.39, -5.93, 55.43)
Coordinate Operation:
- name: Irish Grid
- method: Transverse Mercator
Datum: TM65
- Ellipsoid: Airy Modified 1849
- Prime Meridian: Greenwich
```

In [37]:
```
# create a new shapefile combining the radon and the counties data
radon_counties_gdf.to_file('data_files/radon_counties.shp')
```

```
<ipython-input-37-8f34627e6942>:2: UserWarning: Column names longer than 10 characters will be truncated when saved to
ESRI Shapefile.
  radon_counties_gdf.to_file('data_files/radon_counties.shp')
```

In [38]:
```
# load the new shapefile
radon_counties = gpd.read_file('data_files/radon_counties.shp') # load the radon counties shapefile
```

In [39]:
```
# show a brief description of the new shapefile. County Tyrone is the largest in data count
radon_counties.CountyName.describe()
```

Out[39]:
```
count      13855
unique         6
top       TYRONE
freq        3184
Name: CountyName, dtype: object
```

In [40]:
```
radon_counties  # display the attributes of the new shapefile
```

Out[40]:

	COUNTY_ID	CountyName	Area_SqKM	OBJECTID	index_righ	Tile	class	x	y	geometry
0	6	TYRONE	3265.796622	1	11267	H7546	4	275500	346500	POINT (275500.000 346500.000)
1	6	TYRONE	3265.796622	1	11268	H7646	3	276500	346500	POINT (276500.000 346500.000)
2	6	TYRONE	3265.796622	1	11109	H7647	2	276500	347500	POINT (276500.000 347500.000)
3	6	TYRONE	3265.796622	1	11723	H7343	3	273500	343500	POINT (273500.000 343500.000)
4	6	TYRONE	3265.796622	1	11724	H7443	3	274500	343500	POINT (274500.000 343500.000)
...	...	...	...	...	...	...	...	...	...	...
13850	3	DOWN	2491.238606	6	8630	J2662	1	326500	362500	POINT (326500.000 362500.000)
13851	3	DOWN	2491.238606	6	8631	J2762	1	327500	362500	POINT (327500.000 362500.000)
13852	3	DOWN	2491.238606	6	8612	J0862	3	308500	362500	POINT (308500.000 362500.000)
13853	3	DOWN	2491.238606	6	8445	J0863	1	308500	363500	POINT (308500.000 363500.000)
13854	3	DOWN	2491.238606	6	8444	J0763	1	307500	363500	POINT (307500.000 363500.000)

13855 rows × 10 columns

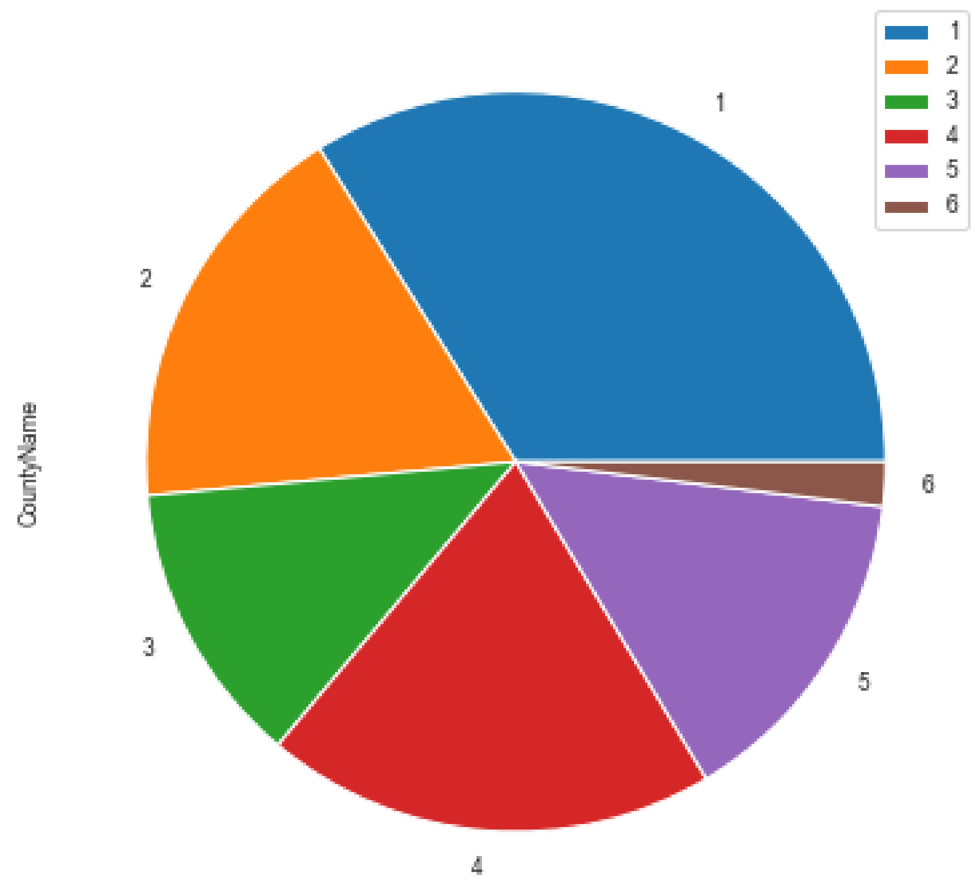
In [41]:
```
# display the data counts of each class
radon_counties.groupby(['class']).count()
```

Out[41]:

	COUNTY_ID	CountyName	Area_SqKM	OBJECTID	index_righ	Tile	x	y	geometry
class									
1	4699	4699	4699	4699	4699	4699	4699	4699	4699
2	2431	2431	2431	2431	2431	2431	2431	2431	2431
3	1721	1721	1721	1721	1721	1721	1721	1721	1721
4	2734	2734	2734	2734	2734	2734	2734	2734	2734
5	2002	2002	2002	2002	2002	2002	2002	2002	2002
6	268	268	268	268	268	268	268	268	268

In [42]:
```
# Pie plot of each class count in the Northern Ireland. Class 1 is the top while class 6 is the lowest
radon_counties.groupby(['class']).count().plot(kind='pie', y='CountyName', figsize=(6, 6));
```

Figure 8



x=−0.861 y=−1.060

In [43]:
```
# summarize the radon distribution within each County.
print(radon_counties.groupby(['CountyName', 'class'])['class'].count())
```

```
CountyName   class
ANTRIM       1        2448
             2         397
             3           7
             4          96
             5           1
             6          11
ARMAGH       1         327
             2         434
             3         283
             4         103
             5         138
             6           3
DOWN         1         656
             2         568
             3         501
             4         331
             5         300
             6         139
FERMANAGH    1         113
             2         273
             3         349
             4         745
             5         305
             6          39
LONDONDERRY  1         964
             2         241
             3         174
             4         303
             5         422
TYRONE       1         191
             2         518
             3         407
             4        1156
             5         836
             6          76
Name: class, dtype: int64
```

In [44]:
```
# Average radon class in each county
radon_counties.groupby("CountyName")["class"].mean()
```

Out[44]:
```
CountyName
ANTRIM         1.256081
ARMAGH         2.456522
DOWN           2.786774
FERMANAGH      3.533443
LONDONDERRY    2.514259
TYRONE         3.677136
Name: class, dtype: float64
```

In [45]:
```
# Average radon class in each county, sorted by the highest.
# County Tyrone shows the highest radon potential level, with an average of 3.68
radon_counties.groupby("CountyName").mean().sort_values(by = "class", ascending = False)
```

Out[45]:

	COUNTY_ID	Area_SqKM	OBJECTID	index_righ	class	x	y
CountyName							
TYRONE	6.0	3265.796622	1.0	7004.829774	3.677136	253130.025126	374022.613065
FERMANAGH	4.0	1850.832538	4.0	11370.660636	3.533443	223566.885965	344410.635965
DOWN	3.0	2491.238606	6.0	10890.040481	2.786774	333823.046092	347807.815631
LONDONDERRY	5.0	2118.316853	5.0	2655.370722	2.514259	273890.209125	409728.136882
ARMAGH	2.0	1327.228438	3.0	12102.815217	2.456522	294173.913043	339005.434783
ANTRIM	1.0	3097.847750	2.0	3355.223986	1.256081	316042.567568	405103.378378

Note that County Tyrone is the largest in area, also display the highest average radon potential risk.

Hence, we will focus on this county for a bit of time to understand the radon distribution in this specific county

In [46]:
```
# subset the data, i.e. create a new dataset representing the radon distribution in the County Tyrone
county_tyrone = radon_counties[radon_counties.CountyName == "TYRONE"]
len(county_tyrone) # returns the number of radon data (data count) in county Tyrone
```

Out[46]:
```
3184
```

In [47]:
```
county_tyrone # display the Tyrone dataset
```

Out[47]:

	COUNTY_ID	CountyName	Area_SqKM	OBJECTID	index_righ	Tile	class	x	y	geometry
0	6	TYRONE	3265.796622	1	11267	H7546	4	275500	346500	POINT (275500.000 346500.000)
1	6	TYRONE	3265.796622	1	11268	H7646	3	276500	346500	POINT (276500.000 346500.000)
2	6	TYRONE	3265.796622	1	11109	H7647	2	276500	347500	POINT (276500.000 347500.000)
3	6	TYRONE	3265.796622	1	11723	H7343	3	273500	343500	POINT (273500.000 343500.000)
4	6	TYRONE	3265.796622	1	11724	H7443	3	274500	343500	POINT (274500.000 343500.000)
...	...	...	...	...	...	...	...	...	...	...
3179	6	TYRONE	3265.796622	1	2414	C3910	4	239500	410500	POINT (239500.000 410500.000)
3180	6	TYRONE	3265.796622	1	2411	C3610	4	236500	410500	POINT (236500.000 410500.000)
3181	6	TYRONE	3265.796622	1	2412	C3710	4	237500	410500	POINT (237500.000 410500.000)
3182	6	TYRONE	3265.796622	1	2725	C4307	5	243500	407500	POINT (243500.000 407500.000)
3183	6	TYRONE	3265.796622	1	2622	C4408	5	244500	408500	POINT (244500.000 408500.000)

3184 rows × 10 columns

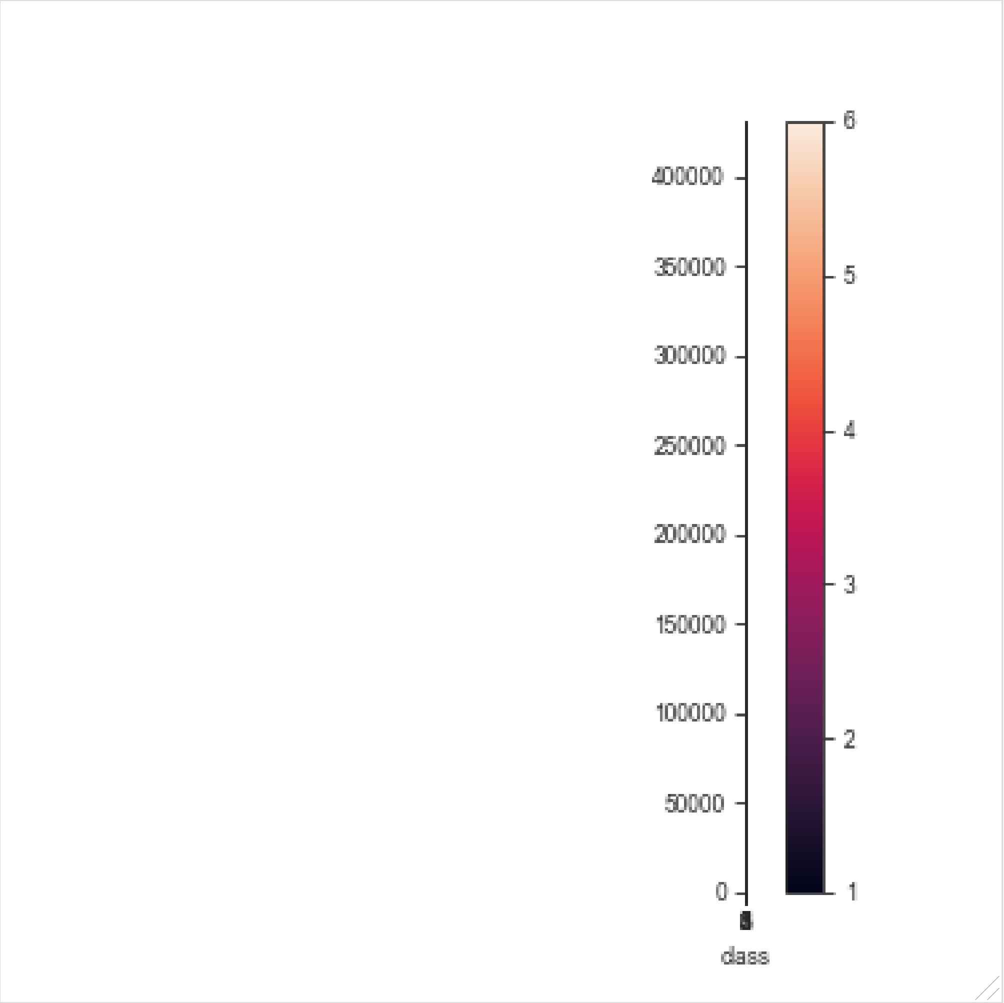
In [48]:
```
# show the maximum and minimum class values in County Tyrone
county_tyrone.loc[[county_tyrone["class"].idxmax(), county_tyrone["class"].idxmin()]]
```

Out[48]:

	COUNTY_ID	CountyName	Area_SqKM	OBJECTID	index_righ	Tile	class	x	y	geometry
413	6	TYRONE	3265.796622	1	6873	H8474	6	284500	374500	POINT (284500.000 374500.000)
81	6	TYRONE	3265.796622	1	10280	H7952	1	279500	352500	POINT (279500.000 352500.000)

In [49]:
```
# plot the radon distribution in County Tyrone.
# Higher radon classes in the northern parts of the county compared to the southern parts.
county_tyrone.plot(column='class', cmap=None, legend=True, figsize=(5, 5));
```

Figure 9



Left button pans, Right button zooms x/y fixes axis, CTRL fixes aspect

In [50]:
```
# calculate the class percentages. Note that total data count is = 3184
tyrone_class_percent = (county_tyrone.groupby(['class'])['class'].count() * 100 / 3184)
tyrone_class_percent
```

Out[50]:
```
class
1     5.998744
2    16.268844
3    12.782663
4    36.306533
5    26.256281
6     2.386935
Name: class, dtype: float64
```

In [51]:
```
# plot the classes. Note that Class 4 is the highest in the county
ax = tyrone_class_percent.plot.bar(x='class', y='%', rot=0)
```

In [52]:
```
county_tyrone.crs #check CRS
```

Out[52]:
```
<Projected CRS: EPSG:29902>
Name: TM65 / Irish Grid
Axis Info [cartesian]:
- E[east]: Easting (metre)
- N[north]: Northing (metre)
Area of Use:
- name: Ireland - onshore.
- bounds: (-10.56, 51.39, -5.93, 55.43)
Coordinate Operation:
- name: Irish Grid
- method: Transverse Mercator
Datum: TM65
- Ellipsoid: Airy Modified 1849
- Prime Meridian: Greenwich
```

In [53]:
```
# save Tyron data to a new shapefile
county_tyrone.to_file('data_files/radon_tyrone.shp')
```

```
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
```

7. Bedrock Geology

==

In [54]:
```
bedrocks.shape # datasets are made up of 2263 rows (records) and 5 columns (attributes)
```

Out[54]:
```
(2263, 5)
```

In [55]:
```
# Read the bedrocks dataset
bedrocks
```

Out[55]:

	MSLINK_0	UnitName	Code	area	geometry
0	3678	ACID VOLCANICS	5	4.171498e+05	POLYGON ((306027.195 353143.694, 306147.747 35...
1	3678	ACID VOLCANICS	5	8.885223e+05	POLYGON ((305968.411 353228.661, 306164.238 35...
2	3659	ACID VOLCANICS	5	5.596615e+04	POLYGON ((313527.461 407868.052, 313589.811 40...
3	3663	ACID VOLCANICS	5	9.072705e+04	POLYGON ((325888.569 386805.060, 325974.534 38...
4	3659	ACID VOLCANICS	5	1.247527e+05	POLYGON ((311478.844 406950.057, 311603.542 40...
...	...	...	...	...	...
2258	3602	SANDSTONE	8	1.299333e+08	POLYGON ((275379.821 345384.076, 275448.622 34...
2259	3689	SANDSTONE	8	2.949386e+05	POLYGON ((344783.212 372882.594, 344956.610 37...
2260	3581	SANDSTONE	8	3.032128e+05	POLYGON ((310257.133 438486.495, 310370.824 43...
2261	0	SANDSTONE	8	1.311301e+01	POLYGON ((262865.226 428766.507, 262868.173 42...
2262	0	SANDSTONE	8	2.384296e+01	POLYGON ((247234.616 421601.542, 247238.460 42...

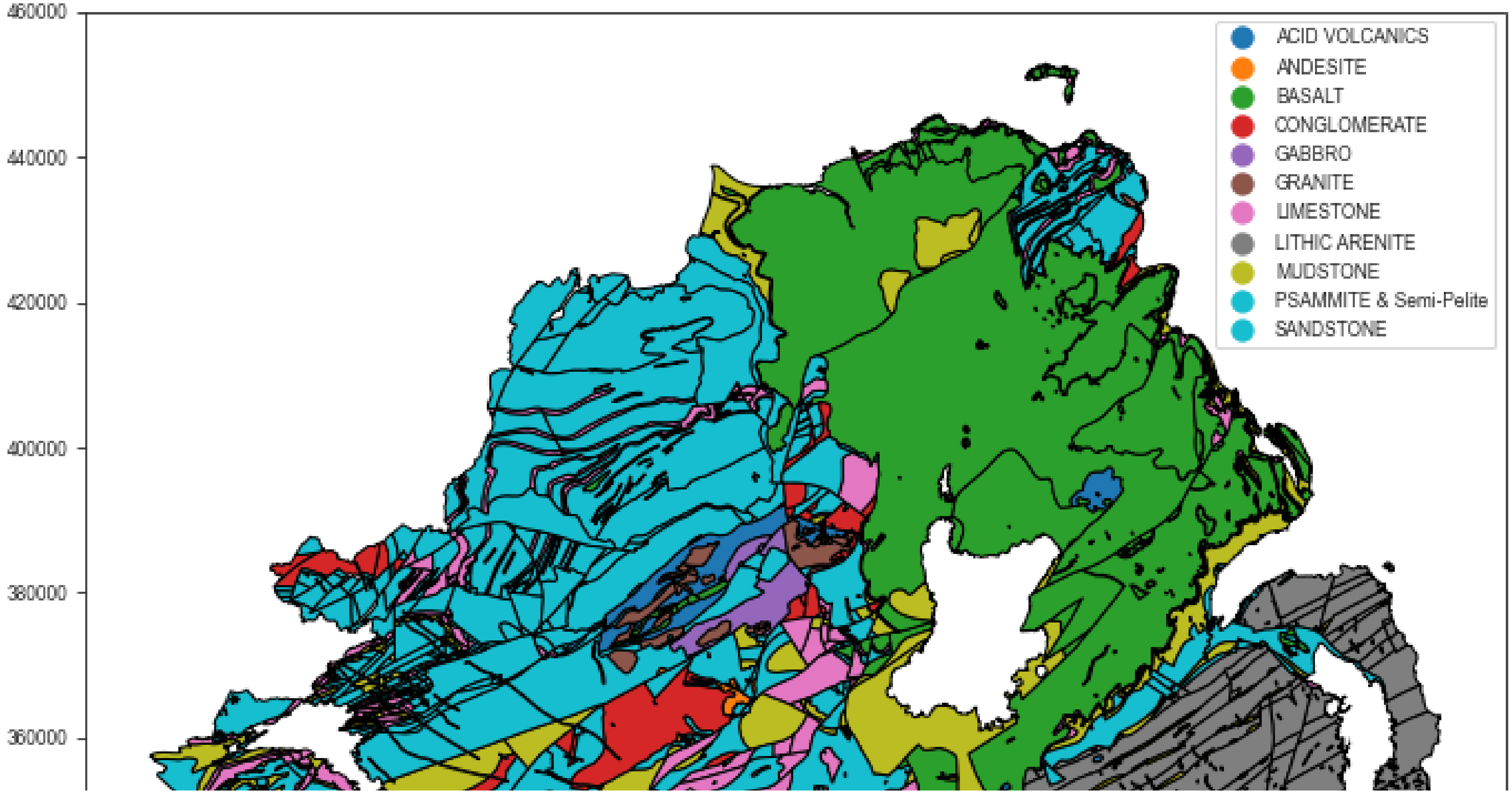
2263 rows × 5 columns

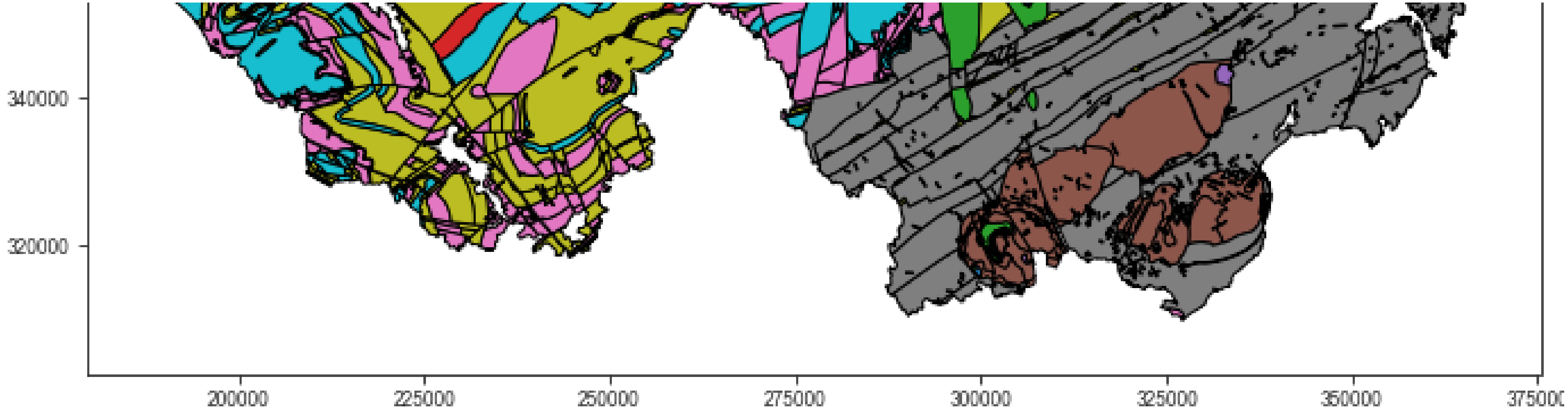
In [56]:
```
# view the number of bedrock types
bedrocks['UnitName'].describe()
```

Out[56]:
```
count          2263
unique           11
top       LIMESTONE
freq            492
Name: UnitName, dtype: object
```

In [57]:
```
# Plot the bedrock dataset with symbology and legend
bedrocks.plot(column='UnitName', edgecolor="black", cmap=None, legend=True, figsize=(11, 10))
```

Figure 10





Out[57]: `<AxesSubplot:>`

Note that the basalt (green colour) occupies most of the northeastern part of the area, while lithic arenites (grey colour),a type of sandstones, is dominant in the southeastern parts. The western part of the country is represented by complex distribution of various rocks. Granites bodies can be observed in various parts of the maps but form large pluton in the southeast.

In [58]:
```
bedrocks.crs # check coordinates
```

Out[58]:
```
<Projected CRS: EPSG:29902>
Name: TM65 / Irish Grid
Axis Info [cartesian]:
- E[east]: Easting (metre)
- N[north]: Northing (metre)
Area of Use:
- name: Ireland - onshore.
- bounds: (-10.56, 51.39, -5.93, 55.43)
Coordinate Operation:
- name: Irish Grid
- method: Transverse Mercator
Datum: TM65
- Ellipsoid: Airy Modified 1849
- Prime Meridian: Greenwich
```

In [59]:
```
# show the number of polygons representing each bedrock type
bedrocks['UnitName'].value_counts()
```

Out[59]:
```
LIMESTONE                  492
MUDSTONE                   490
SANDSTONE                  346
BASALT                     343
GRANITE                    184
LITHIC ARENITE             174
PSAMMITE & Semi-Pelite     139
CONGLOMERATE                41
ACID VOLCANICS              24
ANDESITE                    18
GABBRO                      12
Name: UnitName, dtype: int64
```

In [60]:
```
# Total area of each lithology in km2. Note that basalt covers the largest area
print(bedrocks.groupby(by=["UnitName"])["area"].sum() /1000000)
```

```
UnitName
ACID VOLCANICS              163.646183
ANDESITE                     20.114958
BASALT                     3419.777337
CONGLOMERATE                341.487118
GABBRO                      100.330584
GRANITE                     624.382891
LIMESTONE                  1108.611318
LITHIC ARENITE             2462.508416
MUDSTONE                   1584.046536
PSAMMITE & Semi-Pelite     1764.213243
SANDSTONE                  1869.394440
Name: area, dtype: float64
```

In [61]:
```
# join the radon and bedrock datasets
radon_bedrocks = gpd.sjoin(bedrocks, radon, how='inner', lsuffix='left', rsuffix='right')
```

In [62]:
```
radon_bedrocks.to_file('data_files/radon_bedrock.shp')
```

```
<ipython-input-62-6d50c6824d40>:1: UserWarning: Column names longer than 10 characters will be truncated when saved to
ESRI Shapefile.
  radon_bedrocks.to_file('data_files/radon_bedrock.shp')
```

In [63]:
```
# read the new dataset
radon_bedrocks
```

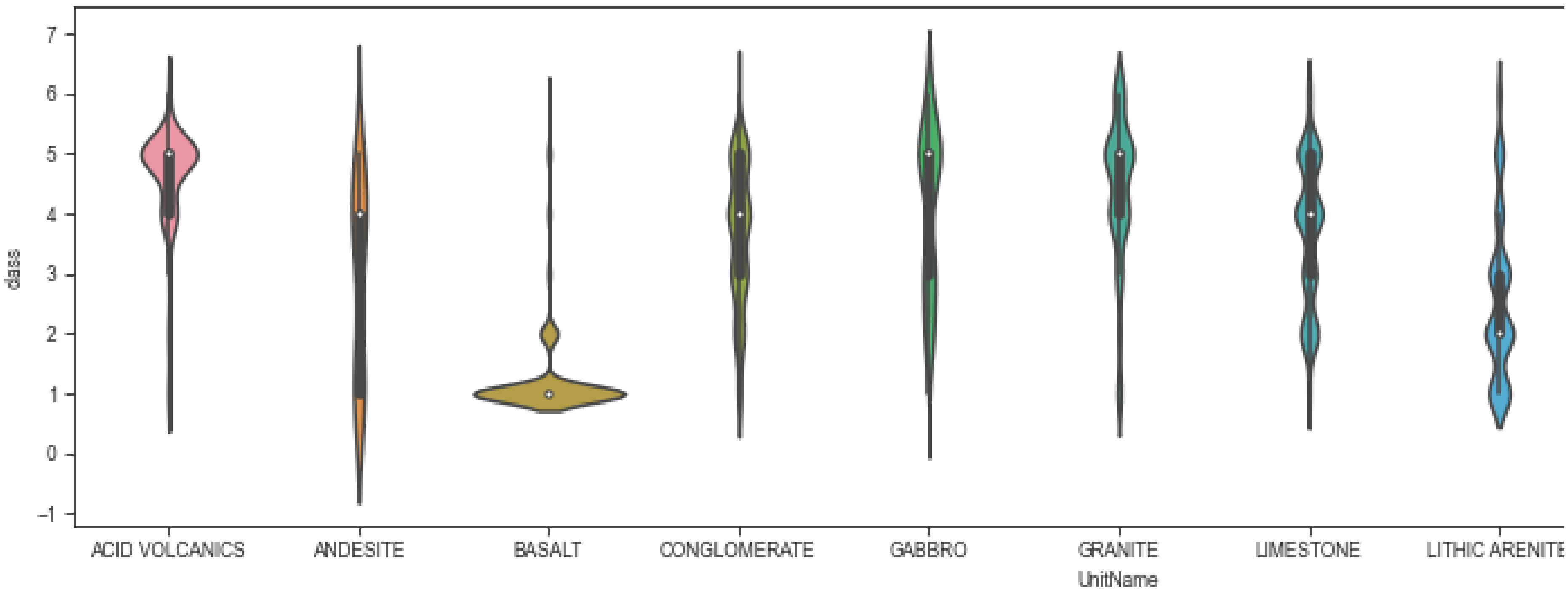
Out[63]:

	MSLINK_0	UnitName	Code	area	geometry	index_right	Tile	class	x	y
1	3678	ACID VOLCANICS	5	8.885223e+05	POLYGON ((305968.411 353228.661, 306164.238 35...	10134	J0653	4	306500	353500
1	3678	ACID VOLCANICS	5	8.885223e+05	POLYGON ((305968.411 353228.661, 306164.238 35...	10307	J0652	1	306500	352500
3	3663	ACID VOLCANICS	5	9.072705e+04	POLYGON ((325888.569 386805.060, 325974.534 38...	5275	J2586	1	325500	386500
4	3659	ACID VOLCANICS	5	1.247527e+05	POLYGON ((311478.844 406950.057, 311603.542 40...	2897	D1106	1	311500	406500
9	3659	ACID VOLCANICS	5	9.223958e+05	POLYGON ((319385.996 357532.585, 319634.394 35...	9453	J1957	1	319500	357500
...	...	...	...	...	...	...	...	...	...	...
2258	3602	SANDSTONE	8	1.299333e+08	POLYGON ((275379.821 345384.076, 275448.622 34...	9413	H7957	2	279500	357500
2258	3602	SANDSTONE	8	1.299333e+08	POLYGON ((275379.821 345384.076, 275448.622 34...	9241	H8058	2	280500	358500
2258	3602	SANDSTONE	8	1.299333e+08	POLYGON ((275379.821 345384.076, 275448.622 34...	8908	H8160	2	281500	360500
2258	3602	SANDSTONE	8	1.299333e+08	POLYGON ((275379.821 345384.076, 275448.622 34...	8907	H8060	2	280500	360500
2258	3602	SANDSTONE	8	1.299333e+08	POLYGON ((275379.821 345384.076, 275448.622 34...	8910	H8360	2	283500	360500

13463 rows × 10 columns

In [64]:
```
# distribution of various classes within each bedrock type.
# code adapted from: https://stackoverflow.com/questions/31594549/how-do-i-change-the-figure-size-for-a-seaborn-plot
sns.set_style('ticks')
fig, ax = plt.subplots()

# set the size of the graph
fig.set_size_inches(16, 4)

sns.violinplot(x = "UnitName", y = "class", data = radon_bedrocks)

#save the figure as an image
fig.savefig('data files/radon bedrocks.png')
```

Figure 11



Bedrocks classed as acid volcanics, granites and gabbros show show the highest median values and the highest probabilities of high radon classes. In the meantime, basalt bedrock are more likely to be associated with the lowest radon levels.

= =

8. Digital Terrain Model Data

= =

In [65]:
```
# Open the raster and store metadata
dtm = rio.open('data_files/ni_dtm.tif')
```

In [66]:
```
#View raster information
print('{} opened in {} mode'.format(dtm.name,dtm.mode))
print('image has {} band(s)'.format(dtm.count))
print('image size (width, height): {} x {}'.format(dtm.width, dtm.height))
print('band 1 dataype is {}'.format(dtm.dtypes[0])) # note that the band name (Band 1) differs from the list index [0]
```

```
data_files/ni_dtm.tif opened in r mode
image has 1 band(s)
image size (width, height): 3559 x 2867
band 1 dataype is int16
```

In [67]:
```
print(dtm.bounds)
```

```
BoundingBox(left=188566.06416642142, bottom=309840.37988014915, right=366516.0641664214, top=453190.37988014915)
```

In [68]:
```
print(dtm.crs)
```

```
EPSG:29902
```

In [69]:
```
# Read points from shapefile
pts = radon
pts = pts[['x', 'y', 'class', 'geometry']]
pts.index = range(len(pts))
coords = [(x,y) for x, y in zip(pts.x, pts.y)]

# Sample the raster at every point location and store values in DataFrame
# adapted after: https://gis.stackexchange.com/questions/345428/reading-raster-values-in-points-gives-back-a-generator-ol
pts['Value'] = [x[0] for x in dtm.sample(coords)]
```

In [70]:
```
# pairing the xy with the geometry
zip(pts.geometry.x, pts.geometry.y)
```

Out[70]:
```
<zip at 0x20916247800>
```

In [71]:
```
# show the raster values (elevation in m)
pts['Value']
```

Out[71]:
```
0          0
1          0
2          0
3          0
4          0
        ...
14715    122
14716      0
14717      0
14718      0
14719      0
Name: Value, Length: 14720, dtype: int64
```

In [72]:
```
pts.crs #  show the coordinates of the dataset
```

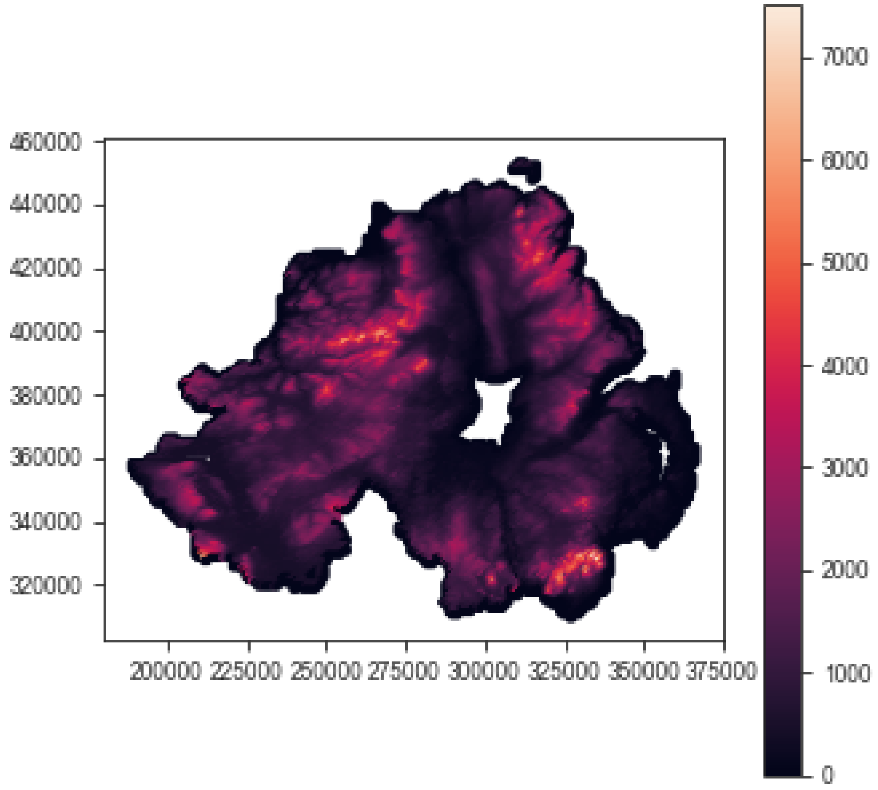
Out[72]:
```
<Projected CRS: EPSG:29902>
Name: TM65 / Irish Grid
Axis Info [cartesian]:
- E[east]: Easting (metre)
- N[north]: Northing (metre)
Area of Use:
- name: Ireland - onshore.
- bounds: (-10.56, 51.39, -5.93, 55.43)
Coordinate Operation:
- name: Irish Grid
- method: Transverse Mercator
Datum: TM65
- Ellipsoid: Airy Modified 1849
- Prime Meridian: Greenwich
```

In [73]:
```
# create a new shapefile of the radon and elevation data
pts.to_file('data_files/radon_dtm.shp')
```

In [74]:
```
# load the shapefile
radon_dtm = gpd.read_file('data_files/radon_dtm.shp')
```

In [75]:
```
# Show the elevation distribution
radon_dtm.plot('Value', legend=True, figsize=(5, 5), markersize=5);
```

Figure 12



In [76]:
```
# show the dataset
radon_dtm
```

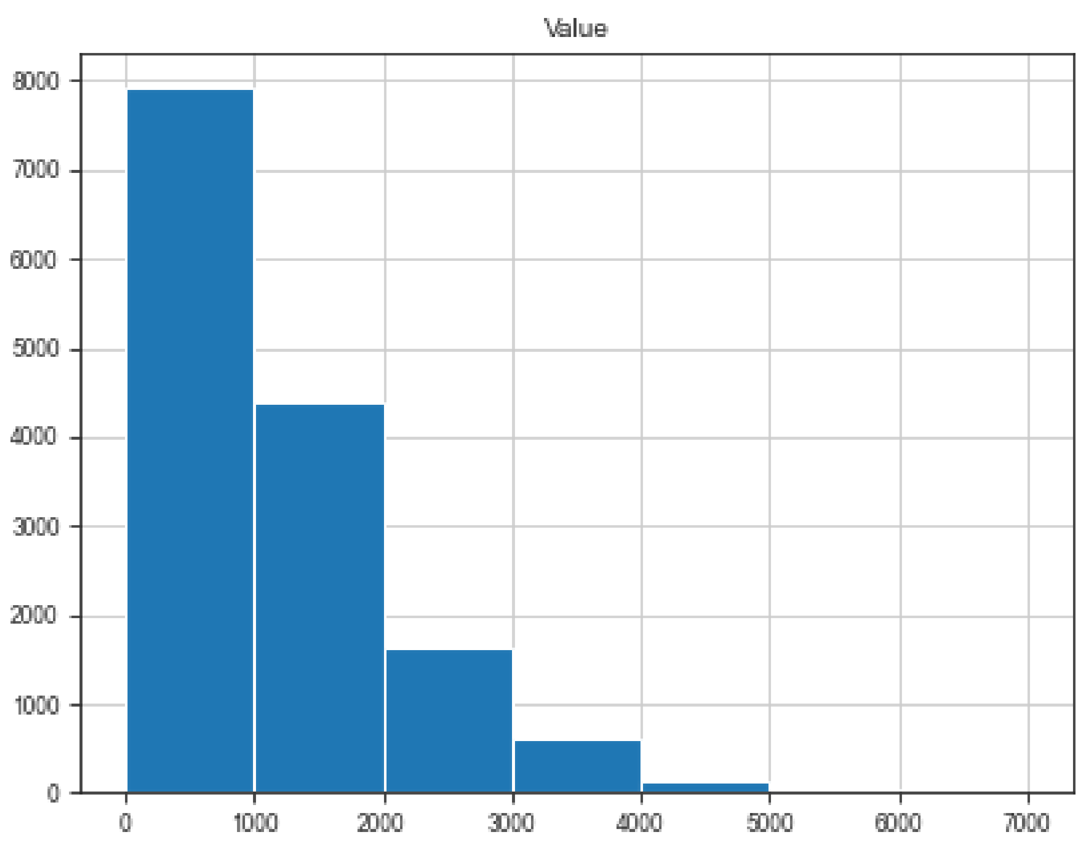
Out[76]:

	x	y	class	Value	geometry
0	310500	453500	1	0	POINT (310500.000 453500.000)
1	311500	453500	1	0	POINT (311500.000 453500.000)
2	312500	453500	1	0	POINT (312500.000 453500.000)
3	309500	452500	2	0	POINT (309500.000 452500.000)
4	310500	452500	2	0	POINT (310500.000 452500.000)
...	...	...	...	...	...
14715	327500	310500	5	122	POINT (327500.000 310500.000)
14716	328500	310500	4	0	POINT (328500.000 310500.000)
14717	329500	310500	4	0	POINT (329500.000 310500.000)
14718	326500	309500	4	0	POINT (326500.000 309500.000)
14719	327500	309500	4	0	POINT (327500.000 309500.000)

14720 rows × 5 columns

In [77]:
```
# histogram of elevation data
radon_dtm.hist(column='Value', bins=[0,1000,2000,3000,4000,5000,6000,7000]);
```

Figure 13



In [78]:
```
# Show the average ground elevation corresponding to each radon class
DTM_mean=radon_dtm.groupby("class").mean().sort_values(by = "Value", ascending = False)
DTM_mean
```

Out[78]:

class	x	y	Value
5	265557.294174	368956.427540	1603.001926
6	292583.333333	344150.000000	1418.330000
4	258623.614958	364056.440443	1213.928324
3	278087.171053	358404.605263	1085.328947
1	305618.378812	392035.112360	1006.031701
2	292103.324518	368635.247450	950.794862

In general, high radon class values are associated with high terrain elevations. This could be explained with the association with granites, gabbro and acid volcanics that usually form hard substrates and high mountains, less affected by erosion.

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Summary and conclusions

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- **County Tyrone** shows the highest radon potential levels while County Antrim shows the lowest levels.
- High radon classes are associated with **granitic**, **gabbroic** and **acid volcanic rocks**. In contrast, lower radon classes are observed over areas underlaid by basaltic and sedimentary bedrocks.
- Higher radon potential levels are recorded in **elevated terrains** compared to low-lands.