FIRAT UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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ON PHYSICAL MECHANISMS OF RADON TRANSPORT FROM SOIL TO AIR

Saleem JASIM

Master's Thesis

DEPARTMENT OF PHYSICS

Division of Nuclear Physics

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This thesis, which was prepared according to the thesis writing rules of the Graduate School of Natural and Applied Sciences, Fırat University, was evaluated by the committee members who have signed the following signatures and was unanimously approved after the defense exam made open to the academic audience.

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DECLARATION

I hereby declare that I wrote this Master's Thesis titled " On Physical Mechanisms of Radon Transport from Soil to Air" in consistent with the thesis writing guide of the Graduate School of Natural and Applied Sciences, Firat University. I also declare that all information in it is correct, that I acted according to scientific ethics in producing and presenting the findings, cited all the references I used, express all institutions or organizations or persons who supported the thesis financially. I have never used the data and information I provide here in order to get a degree in any way.

01 July 2020

Saleem JASIM

PREFACE

This thesis provides a comprehensive overview of the radon releases from ground soil to the atmosphere, and other factors controlling the radon migration process describes radon characteristics and its benefits as a tracer for earthquake prediction with time series analysis.

I would like to express my sincere gratitude to my research supervisor Prof. Dr. Fatih KÜLAHCI for the continuous support of my study and research, for his patience, motivation, enthusiasm, and immense knowledge. Besides my supervisor, I wish to express my deepest gratitude to Dr. Ibrahim Nazem QADIR for his invaluable assistance, support, and encouragement.

I would like to pay my special regards to my family for their patience, prayers, I am indebted to my deceased parent mother Masome Yousif who lost her life during my primary school studies whose prayers I always feel and I wish her God's mercy and my deceased father Mohammed shareef, whose prayers keep me going throughout. moreover, I thank my family members for making this dream come true, and my friends

Saleem JASIM
ELAZIG, 2020

TABLE OF CONTENTS

ABSTRACT

On Physical Mechanisms of Radon Transport from Soil to Air

Saleem JASIM

Master's Thesis

FIRAT UNIVERSITY
Graduate School of Natural and Applied Sciences

Department of Physics

July 2020, Page: xi + 76

Since the prediction of earthquakes is an object of controversies, studies continue to work on this issue. radon observing site was located in Turkey/ Erzincan / Ekşisu, Radon Data has been given by the General Directorate of Disaster Affairs of the Prime Ministry following the scientific agreement we have made so that we can use scientific studies. Historical earthquake data within 100 km of Ekşisu will be supplied from Bogazici University Kandilli observatory. this thesis provides a comprehensive overview of the radon releases from the ground to the atmosphere, and other factors controlling radon migration processes, such as Surficial radionuclide content in the soil, radon emanation coefficient, radon diffusivity, soil's porosity, permeability, temperature, and pressure effects, furthermore, describes radon characteristics and its aids as a tracer for earthquake prediction, by time series analysis. herein, tried to demonstrate the correlation between variables by drawing graphs that manifesting the anomalies of radon concentration with earthquakes and meteorological effects. consequently, many studies made certain that no significant change has been seen in Radon anomaly in the same season of different years, except the abnormal radon concentration change before /after and during the mainshock of the quake can be seen that radon release strongly correlated with earthquakes activities.

Keywords: Radon gas, Time series, Seismic precursor, Meteorological data.

ÖZET

Topraktan Havaya Radon Taşınımının Fiziksel Mekanizmaları Üzerine

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Deprem öngörüleri üzerine bilimsel araştırmalar önemini korumakta ve bu yönde yoğun bir şekilde devam etmektedir. Bu araştırmada, Kuzey Anadolu Fay Zonu üzerinde yer alan Erzincan-Ekşisu Radon gözlem istasyonundan alınan veriler değerlendirildi. Ekşisu'ya 100 km uzaklıktaki tarihi deprem verileri Boğaziçi Üniversitesi Kandilli Rasathanesi'nden sağlandı. Toprağın yüzeysel radyoçekirdek içeriği,Bu tez, topraktan atmosfere radon salınımları ve topraktaki yüzeysel radyonüklid içeriği, radon yayılma katsayısı, radon yayılımı, toprağın gözenekliliği, geçirgenlik, sıcaklık ve basınç etkileri gibi radon göç sürecini kontrol eden diğer faktörlere kapsamlı bir genel bakış sağlar. ayrıca radon karakteristiklerini ve yardımcılarını zaman serileri analiziyle deprem tahmini için izleyici olarak tanımlar. burada radon konsantrasyonunun anormalliklerini depremler ve meteorolojik etkilerle gösteren grafikler çizerek değişkenler arasındaki korelasyonu göstermeye çalıştık. sonuç olarak, birçok çalışma, depremden önceki ve sonraki ve sonrası anormal radon konsantrasyonu değişikliği dışında radon salınımının depremlerle güçlü bir şekilde ilişkili olduğu açıkça görülüyor faaliyetler.

Anahtar Kelimeler: Radon gazı, Zaman serisi, Sismik öncü, Meteorolojik veri

LIST OF FIGURES

Page

LIST OF TABLES

Page

SYMBOLS AND ABBREVIATIONS

Symbols

λ	: decay constant
D	: Diffusion of Radon
D_e	: Effective diffusivity
J^d	: Diffusive Rn-flux to the atmosphere
A_{R_e}	: Radium content of soil
R_m	: Recoil Emanation
I_a	: Radon concentration activity
^{222}Rn	: Radon

Abbreviations

CMB	Cosmic Microwave Background
BBN	Big Bang Nucleosynthesis
EQ	Earthquake
SRG	Soil Radon Gas
NAFZ	North Anatolian Fault Zone
EAFZ	East Anatolian Fault Zone
RDPs	Radon Decay Products or (Radon progeny)
GEM	Global Earthquake Model
ISC-EHB	International Seismological Centre - Engdahl, vander Hilst, and Buland
USGS	United States Geological Survey
NASA	National Aeronautics and Space Administration
MTA	General Directorate of Mineral Research and Exploration of Turkey
NEIC	National Earthquake Information Center
NCRP	National Council for Radon Protection
ICRP	International Commission on Radiological Protection
RCs	Radon Concentrations
ER	Recoil Energy
Bq	Becquerel
dps	Disintegration per second
Ma	Million years ago
Ga	Giga years, or 10^9 years
ppm	parts per million
KeV	Kilo electron volts

1. INTRODUCTION

It is familiar that radon is one of the foremost gas tracers for earthquake foresight science and earthquake identifications Among the trace species in the Earth's crust are elements in the radioactive decays series of three primordial radionuclides, ^{238}U, ^{235}U, and ^{232}Th, the three decay chains share an important feature: Each contains an isotope of radon gas which is the heaviest noble gas. Being chemically inert, radon atoms generated in crustal materials may enter the pore fluids and migrate a significant distance from the site of generation, even during their brief lifetime. (The respective half-lives are 3.8232 days for Radon, 4 s for Actinon, and 56 s for Thoron). By this means, a fraction of the radon generated in rock and soil near the Earth's surface enters the atmosphere before undergoing radioactive decay [1-3].

Radon's properties averred to its use as a geophysical tracer for locating buried faults and geological structures, in exploring or uranium, and for predicting earthquakes. Radon has also been used as a tracer in the study of atmospheric transport processes.

The following conceptual model of radon entry has emerged over the past two decades:

1. The soil is considered to be homogeneous concerning radium content, radon emanation coefficient, porosity, diffusivity, and permeability.

2. The soil is considered to be isotropic concerning permeability.

3. Except in accounting for the effect of buoyancy, the air is treated as incompressible because of the very small disturbance pressures that induce flow.

4. Radon is assumed to migrate through the soil pore air by a combination of advection and diffusion.

5. Radon enters a building primarily by adjective transport of soil gas across openings in the substructure.

6. Soil gas flow into a building is induced by the same forces that drive outdoor air through the building: wind, indoor-outdoor temperature differences, the operation of exhaust fans, and so on.

Radon gas is discovered in the last century and for the first time indicated radon anomalous increases in groundwater before the 1966 Tashkent seismic activity [4]. Radon gas identified one of the seventh earthquakes precursors[5]. Nevertheless reported in some investigations that radon individually does not utilize as a reliable prediction[6]. According to the study of the features of soil radon gas anomaly that can increase abruptly before the quake Occurs, it used as a precursor for the earthquake prediction, conclusions represent those radon variations during the migration in the geosphere by molecular diffusion or convection in the soil to the atmosphere is quite complex. Due to understanding better the radon migration, therefore Soil composition has been studied and Soils that have a granite constituent have more radon concentration than non-granite soils [7]. And radon is the greatest radioactive supply in the environment [8]. That was created naturally by the alpha-decay of radium in the uranium decay chain. Three-fourths of radioactivity produced naturally in the earth [9]. Furthermore used to discover and mapping of the active fault zone [10]. Uranium exploration[11]. And geologists confirm that radon surveying is the most credible geochemical tracer for ore bodies at depth 200 m especially for radon parents in the bedrocks like Uranium [12].

Turkey is the most active region for the strong shallow quakes around the world. because of its complex geotectonic structure. that located within the Alpine-Mediterranean orogenic belt Therefore, it is an active place for volcanoes and tectonism and experiences frequent seismic events [13]. The average RCs levels in the NAFZ are comparatively higher than the EAFZ. that RCs ranged from 4.3 to 9.8 kBq/m^3 for both faults zone. The radon computation system is determined to be a helpful way for earthquake precursor phenomena, hence SRG study is affected by the environmental parameters including, meteorological factors that, suchlike seasonal temperatures or humidity, pressure, geophysics phenomena such as stress-strains in faults line by seismic activity, earthquake magnitude, and depth distance from the surficial crust. and geochemical effects such as the amount of radon supply parents in the composition of the lithosphere, and the porosity of the soil, grain size for soil permeability potential that is useful for radon emanation [14]. And diffusion Fick's law will discern that under standard needed conditions, radon will diffuse simply a few meters from its locality of formation the small amount of radon gas that can discharge from the soil but abnormal RCs can be seen along active fault zones before and during the earthquake and by the deformation of plate's tectonics and remarkable properties and specific characteristics of ^{222}Ra [15]. Because radon gas naturally obtains directly from radium decay which has in the decay chain of ^{238}U which is one of the heaviest radioactive that exist in all types of rocks, soil, deposits, and volcanoes on earth's crust and its isotope formation of natural uranium is 99.27% ^{238}U with a half-life of 4.468 $\times 10^9$ y [16]. Previous studies have shown that changes in RCs along the active fault zone around the world that can be observed by passive and active methods [17,18]. With the observation of the increase in the anomalies in the soil radon gas, the date of the earthquake can be almost predicted [19-21].

The radium content of soil and rock is typically expressed as an activity concentration per unit mass, the radium content in these terms is equivalent to the total production rate of radon in the soil. A radium content of (1 Bq kg^{-1}) implies a total radon production rate of 1 atom kg^{-1}s^{-1}, corresponding to 0.0076 Bq kg^{-1} h^{-1} for ^{222}Rn or 45 Bq kg $^{-1}$ h $^{-1}$ for ^{220}Rn. (The activity concentration of a radioisotope I is related to the number concentration of atoms N by I = N λ, λ is the radioactive decay constant for Radon is 2,0984 x 10^{-2} s^{-1}. The SI unit for activity is the Becquerel (Bq), which, for any radioactive element, corresponds to the number of atoms needed to yield a radioactive decay rate of one per second. The traditional unit of activity, the curie (Ci), is equivalent to 3.7 x 10^{10} Bq.

The radioactive decay constant is related to the half-life; earthquakes are one of the greatest havocking natural perils that reason excessive harm of living. Standardly, ten thousand persons pass away annually as a result of earthquakes[22]. Many studies have been reported the association of SRG anomalies with the earthquake and meteorological parameters and autocorrelation among variables recorded. today scientist's effort is dedicated to identifying statistical analysis and prediction of a probable earthquake based on SRG time-series data [23]. On the other hand, the location and date of earthquake occurrence and magnitude of it are several principal parameters for every earthquake prediction. Moreover, despite the progress of technology methods, scientists and scientific researchers cannot give a definitive answer concerning the anticipation time of seism occurrence, our motivation in this investigation is to study about the radon migration in the soil before ground shaking to predicted earthquake prior to its occurrence, the first time radon was introduced as the pioneering EQ in 1927, nevertheless, the first time radon was recorded before the Tashkent earthquake of 1966 which was announced in many scientific publications to support earthquake forecasting research [24]. Approximately 20 years ago scientists attempted to find a precursor to measuring dissimilar emanations of geo-gases in the earthquake-prone zone around the globe, especially Rn, H_2, He, and CO_2. Among all selected gases, scientists decided to choose radon as the EQ precursor because of its features and it can be easily detectable [25].

Radon is colorless, odorless, and tasteless toxic gas because it is radioactive inert gas which is the progeny of the radionuclide elements in all types of soils and Rocks, furthermore, Radon is one of the heaviest noble gas with highly soluble in water at low temperature and it can be found mainly in the surficial sediments, soil, and granitic rocks[26]. Radon atomic number is 86, it has 39 isotopes from ^{139}Rn to ^{231}Rn and all isotopes are manmade except three of them naturally generating from the environment such as (Radon, Actinon, Thoron) and the most stable among them is ^{222}Rn (Radon) due to its unique half-life (3.823 days) that is the last noble gas that discovered by Friedrich Ernest Dorn [27].

Radon has recoil energy of 86.0 KeV that can help radon to escape from solid grain into pore space, a process called emanation. Radon atoms emanated from the lithosphere and its construction radioactive bases minerals such as ^{238}U and ^{226}Ra in the soil, rocks, then it will migrate through the space of its medium and finally emanate from there to the atmosphere by diffusion (differences in RCs from a high level in the soil to the low level in the atmosphere) and advection (differences in pressure from soil to the air) [28].

The forecasts sufficiently depend on previous phenomena that are so purely experimental and include plenty of practical troubles, although many earthquake predictions are not sufficiently reliable, therefore we ought to be curious to study relevant investigation about seismology, geophysics, geomorphology, utilizing investigations discovery for public welfare because annually thousand earthquakes occurring everywhere on our earth that have the most potential for causing disastrous sufferers, property damage, and economic disruption USA (USGS, 2007), though we have many methods that it can be used to evaluate EQ hazard that has been studied internationally by various ways including (RCs measurement, universal animal behaviors, unified theory for pre-earthquake signals, temperature change, hydrochemical precursors, the water level in see and groundwater, oil wells, the theory of seismic gap, foreshocks, change in seismic wave velocity [29]. The biggest sign for all the above precursors is to delineate abnormal events before the earthquake happening. Unfortunately, claims are not credible predictions for scientific understanding concerning this natural disaster, consequently, researchers try to improve seismic forecasts to can accurately predict the earthquake events. Many reviews concluded that in some cases changes in radon levels preceded an earthquake, as a result, we should investigate on the characteristics of radon gas that how it can penetrate with select most significant effects acting on it during the path in the different mediums with variable emanation fraction for radon for heterogeneous structure of earth suchlike soils, bedrocks [30].

Our dissertation scope is associated with Radon gas in the soil as one of the common tracers and indicators in earthquake prediction research Because of its unique chemical properties [25].

I focused on earlier credible investigations throughout radon geosphere properties, hence, we have analyzed and graphed available Data such as earthquake data with meteorological data intended to our study field. it was tried to interpret the changes by drawing Time Series graphs showing the change of ^{222}Rn concentration with earthquakes. Although noticed there are no big differences in meteorological variables in the same seasons at different dates, it can be said about differences that occurred in the RCs were only caused by seismic activities. Numerous vast efforts were fulfilled to get a credible prediction. nowadays, seismologists and other investigators are continuously have used the best effort to developing modern methods to get practice earthquake predictions to preventing Earthquake losses which recurring annually. an earthquake forecast necessity specifies the time, epicenter, and the magnitude, it will be beneficial certainty that could have serious outcomes on both the natural environment and the society to protect humans' being.

2. THE RELATION BETWEEN EARTHQUAKE AND RADIOACTIVITY

Three suggestions are confident that the Big Bang theory (history of the universe), the universe is expanding every moment by Edwin Hubble Discovery (first evidence) and (CMB) radiation (second evidence) Big Bang Nucleosynthesis is the (third evidence) that tells us that the cosmic chemical evolution process started ≈ 20 minutes after the Big bang occurrence [31-33]. As a result of the above hypothesis, NASA approaches a model of the story of our universe, similar sentences as shown in Figure 2.1.

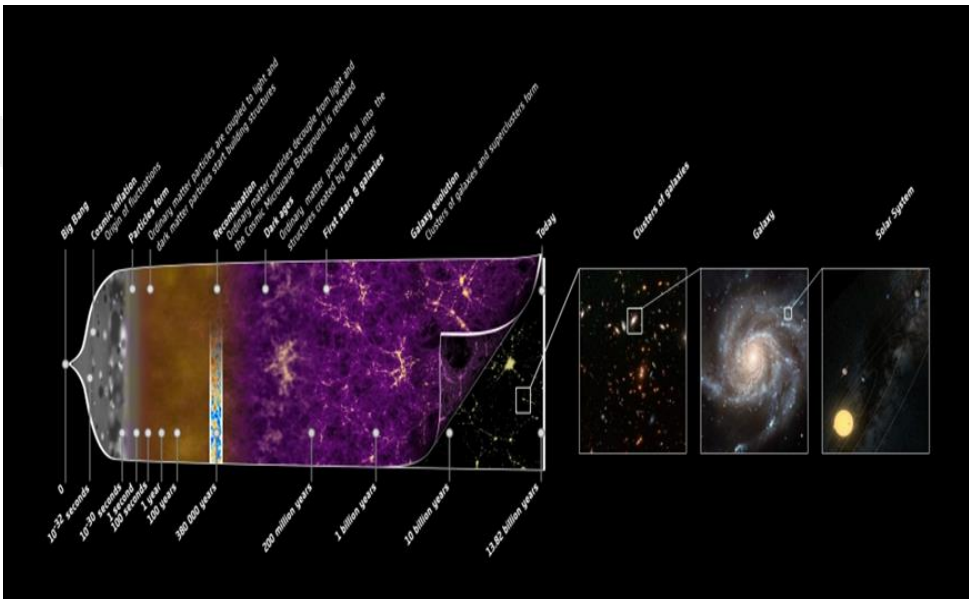

Figure 2.1. This picture compiles approximately 14×10^9 years for a long history of our universe [34]

Solar System Located in Milky Way Galaxy, or our galaxy is composed of the Sun and eight planets. besides, asteroids belt presence between the mars and Jupiter and comets like Halie every 76 years it could complete its orbit in the solar system and the biggest and hottest object in the solar system is the sun itself. As can be seen from Figure 2.2. Herein have astonishing similarity between the smallest part of nature (Atomic system) and (Solar system) which is the concentration of mass in the center of both systems (the atomic Nucleus and the Sun) that hold 99.9% total mass in both systems, moreover, the resemblance between electrons orbits and planets and their spins around itself and the center, and the mechanical forces which dominating the solar system, is gravity force conversely for the Atomic system, is the Coulomb Force, today well-known that atomic form is extra complex, Rutherford-Bohr model has remained a basis for atomic structure [35].

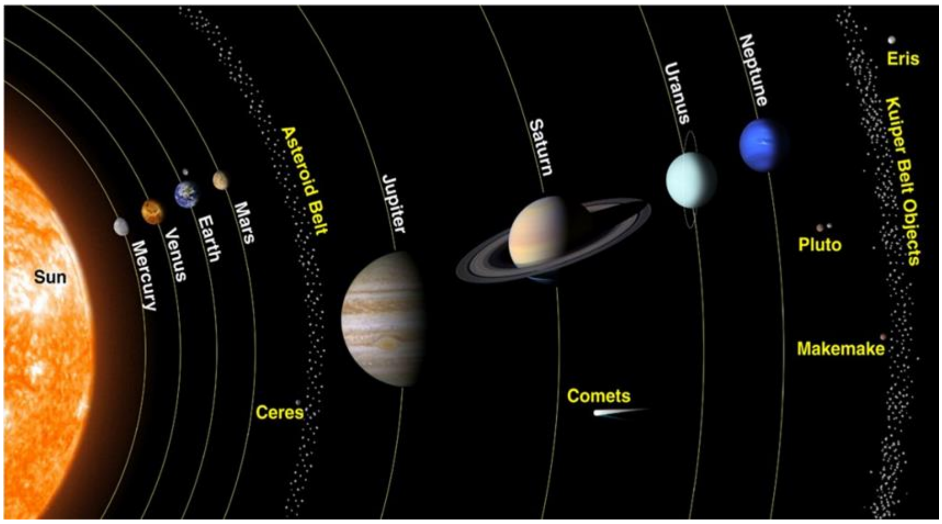

Figure 2.2. The Solar System is not drawn to actual scale [36]

Inner Planets: (Mercury, Venus, Earth, Mars) respectively provided from the nearest planet from the sun are arranged, they can be comparable from outer planets by Rocky planets without rings, closer to the sun, smaller than outer planets in size, hotter temperature, owner lesser moons and faster revolving around the sun.

Asteroids Belt: It attendance between the inner and outer planets that revolving around the sun in the unique orbit that they have many form size from a basketball to 1000 km.

Outer Planets: (Jupiter, Saturn, Uranus, Neptune) respectively arranged from the nearest planet to the sun and they can be comparable from inner planets by huge sizes of gaseous planets with numerous natural moons and unique rings with the coldest surface and extremely have far away from the sun [37, 38].

Kuiper Belt: is the protoplanetary disk observed beyond the Neptune orbit [39]. Newton suggested that short-period comets originated from an icy belt (~200 million bodies of radii 10 km) planetesimals source and evolving place of long-period comets [40].

Erath (Blue Planet): Our Planet is the largest planet in the inner planet and the third closest inner planet to the sun (nearest star to the Earth averagely 15×10^{10} m) with one natural satellite (moon) and many Artificial satellites orbiting it, and earth's mass is 5.9723×10^{24} kg. Earth has 4.5×10^{9} years old, moreover, earth has a phenomenal magnetic field that safe us from the solar winds because of dipole field of the earth's magnetic field becomes harshly bent by Solar Winds [41]. And earth's magnetic field at the equator strength is about 0.35×10^{5} gamma, furthermore, Earth is slightly tilted toward the sun from its geographical dipoles and revolves around the Sun each year once to see four various seasons on both sides of its hemisphere in twelve months, by the reason of unique angular rotation ~23.5° that spins its axis [42]. As can be seen from Figure 2.3.

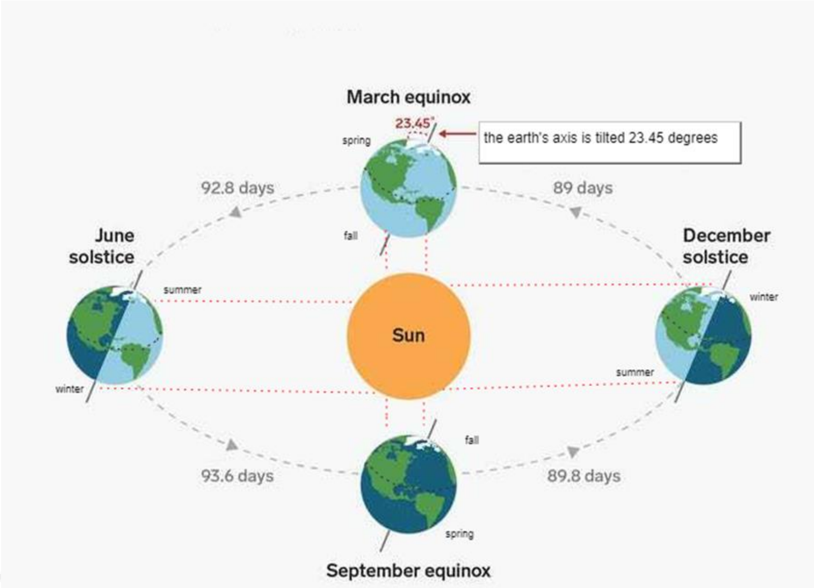

Figure 2.3. The Earth's Solstice and Equinox [43]

Earth's Atmosphere: Earth is an exceptional planet due to its special gravity which has a unique atmosphere that Covered above the earth about 480 Km [44]. By gaseous layers that can sustain life and build our planet as a Green-House habitat for living things in the Hydrosphere and lithosphere or various environments by protecting the water cycle and us from the heat of the sun and its dangerous radiations, the atmosphere contains five layers that are heterogeneous in temperature and properties, including, Troposphere, Stratosphere (Ozone level), Mesosphere, (ionosphere) Thermosphere, and Exosphere Respectively from the nearest layer from the ground toward the uppermost layer of Earth's Atmosphere [45]. Similar sentences as shown in Figure 2.4

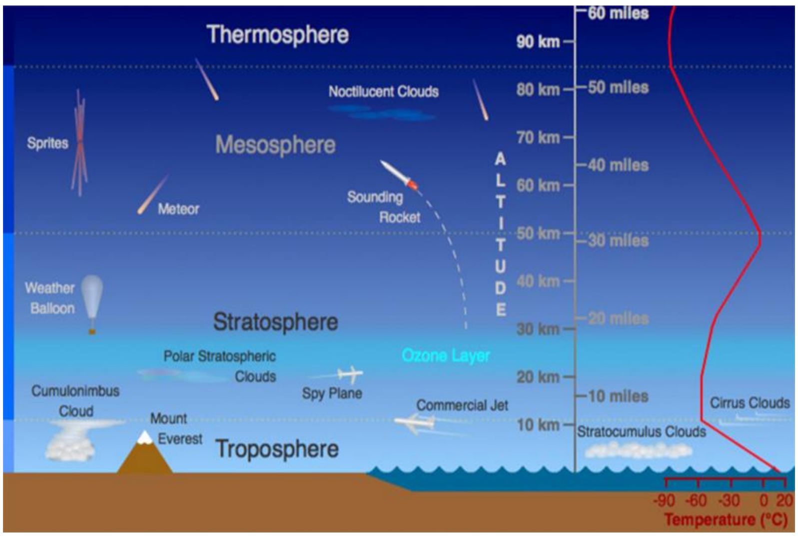

Figure 2. 4. Earth's Atmosphere Layers with their properties[46]

Geosphere of Earth: Our earth is a celestial rocky planet with a radius of 6370 km, its multilayer system, and consists of a diverse layer, following extensive drilling and seismic waves experienced about the inside earth's layers. scientists in two forming Classify Earth's layers at compositional and mechanical. mechanical earth's layers consist of the lithosphere, asthenosphere, mesosphere, outer core, and the inner core. compositional earth's layers consist of such as crust, mantle, and core similar sentences as shown in Figure 2.5 [47, 48]. Earth’s history almost 4.5 billion years old [49].

1- Crust: the uppermost layer of earth with outer silicate solid structure. the constituent of (Si, Al, O, Fe, Ca, Na) its depth estimated approximately 10 km under the oceanic crust to 75 km for continental crust [50].

• Mohorovicic' discontinuity (Moho): is the boundary between the crust and the mantle. seismic waves can variate the velocity by different chemical compositions. The boundary is between 25 and 60 km deep underneath the continents and between 5 and 8 km deep underneath the ocean base [51].

2- Mantel: located under the crust with 2900 km depth, contained Upper and Lower mantel.

Upper mantle: contained the Lithosphere, Asthenosphere [52].

Lithosphere: is the outer solid part of the earth, including the crust and uppermost mantle. It is about 100 km thick, the older lithosphere is thicker .it below the crust is brittle enough at some locations to produce earthquakes by faulting, such as within a subducted oceanic plate [53].

Asthenosphere: located under the Lithosphere that contained a highly viscous molten medium of rocks with a thickness of 200 km approximately. Its Components are (Si, Al, O, Fe,).

Lower mantle: is a malleable layer of mantle located beneath of upper mantle.

Mesosphere: located under the asthenosphere in the lower mantel, composed of solid plastic.

Gutenberg discontinuity: is a transition zone the boundary between mantle and core.

3- Core: divided within two diverse layers inner-core and outer-core.

Outer core: (endosphere): located below of lower mantle, it is liquid with lesser viscosity, its molten rock layer, and thermal convection process is responsible for the generation of earth’s magnetic field. These currents cause a "Geodynamo" phenomenon that results in a magnetic field around the Earth [54]. The main elements in the outer core are nickel (Ni, 90% Fe, S) with a 2350 km radius [52].

Inner core: Are heterogeneity, an elasticity, anisotropy, and super-rotation core and hottest earth’s place which is mostly iron (Fe). with an 1120 km radius. Earth's inner core is 95% iron and is solid despite high temperatures because of its extreme pressure. Therefore, no flow of matter can be assumed in the inner core [55].

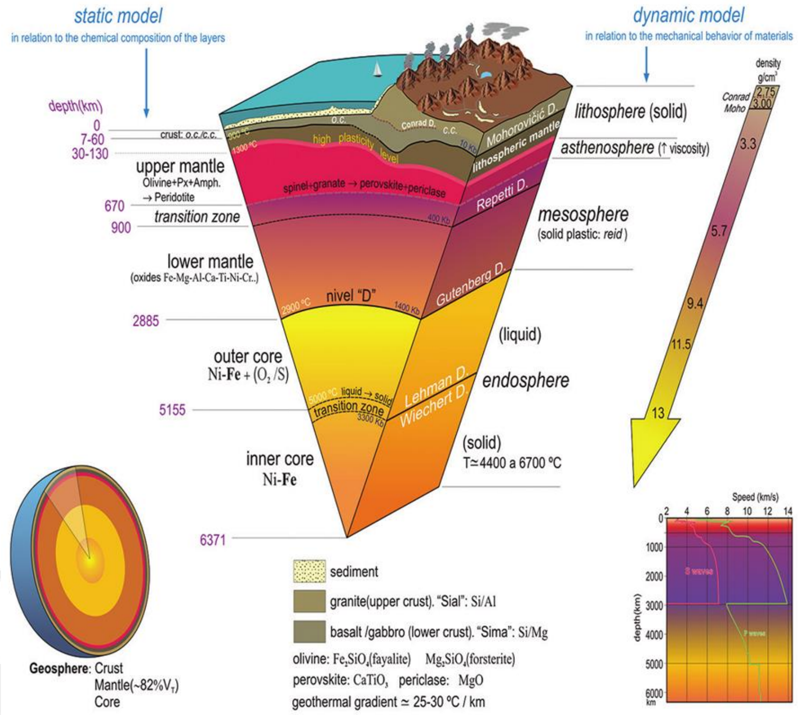

Figure 2. 5. The depiction of both types of earth's layer classifications, chemistry (static model) or mineralogy, and the mechanical pattern of the forming rocks (dynamic model) the layered formation. whereas, containing heat, pressure, density, body wave [52]

Rock Cycle: Each episode of crust formation is usually followed by recycling [56]. This is the restructuring Rocks Processes that occur in the earth's Geosphere, there are three main types of rocks (Igneous, Metamorphic, sedimentary) Rocks given in Figure 2.6. for more information about the rock cycle process.

Igneous rock: while molten rocks were Outburst from inside the earth by the volcano to the land then immediately cooled and hardened then changed to basaltic rocks, when magma gradually crystallizes beneath the ground will change to granite [57].

Sedimentary Rock: is a rock formed from small rock particles, soil, and dead organs, which accumulated, and became hard over time by weathering. Such as Mudstone, Limestone, Sandstone [58].

Metamorphic Rock: formed from other kinds of rocks that are exposed to great heat and pressure. such as Marble and Gneiss [59].

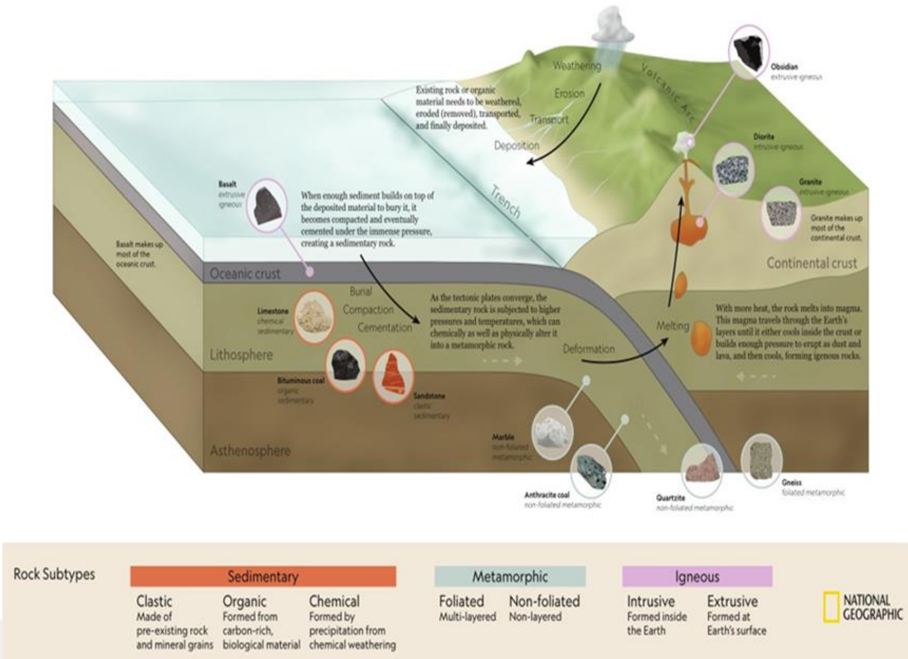

Figure 2. 6. The Rock Cycle [60]

Earth's Soil: Soil is the upper weathering stratum of the earth's crust which is an open system, matters may be added to or removed from it, there is no definition of soil that is approved, Penologists thought of soils are different greatly in their properties, but they have one shared characteristic: they are anisotropic [61]. On the other hand, soil formed commonly from a mixture of minerals, organic matter, gases, liquids, and organisms that have made life Possible together. Soil is the final link between the geosphere layers such as the lithosphere, the atmosphere, the hydrosphere, and the biosphere, and human activities have a remarkable impact on the soil deformation recently. In the polluted soils, the greater portion of heavy metals exists in a mobile form. Contaminated soils hold mobile heavy metals (like (Pb) that is the daughter of (Rn) decay production) more than clean soil [62].

There are two main processes are preceded in the production of soil:

1- Weathering: is a process in which materials on the Earth's surface change according to existing conditions. As can be seen from Figures 2.7, and Figure 2.8.
2- Pedogenesis**:** is a construction process in which the anisotropic complexity of the soil is created from more or less isotropic source materials by additions, losses, translocations, and transformations of their components [63].

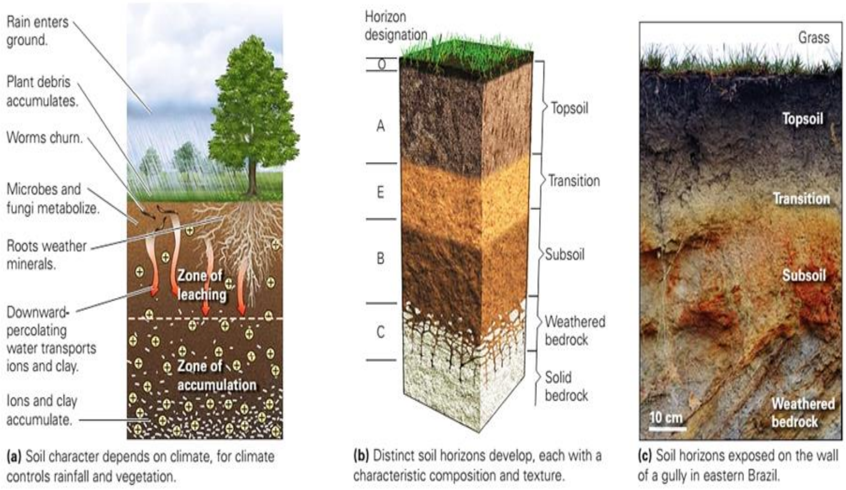

Figure 2. 7. The Formation of soil [64]

Soil can be classified into three main kinds:

1- Desert soil: Precipitation and vegetation play a significant role in determining the type of soil. For example, in the desert, where there are very little precipitation and scattered vegetation, Aridisol is formed (In older classifications, these soils were known as “pedocal” soils).

2- Temperate soil: The alfisol derives this soil possess an O- horizon, and due to a temperate amount of precipitation, the filtered material from the A- horizon will collection the B-horizon. (In the old soil grouping, they were known as the name of soils "pedalfer").

3- Tropical soil: In tropical climates, oxisols are found. due to heavy rainfall, raindrops enter the upper layer of the earth's crust, which is why all active minerals in the soil are chemically exposed and form ions and falling clays. This process caused horizon A to have significant residual content in iron oxide, alumina, and aluminum hydroxides. the soil of the product will be brick red and is traditionally called laterite [65].

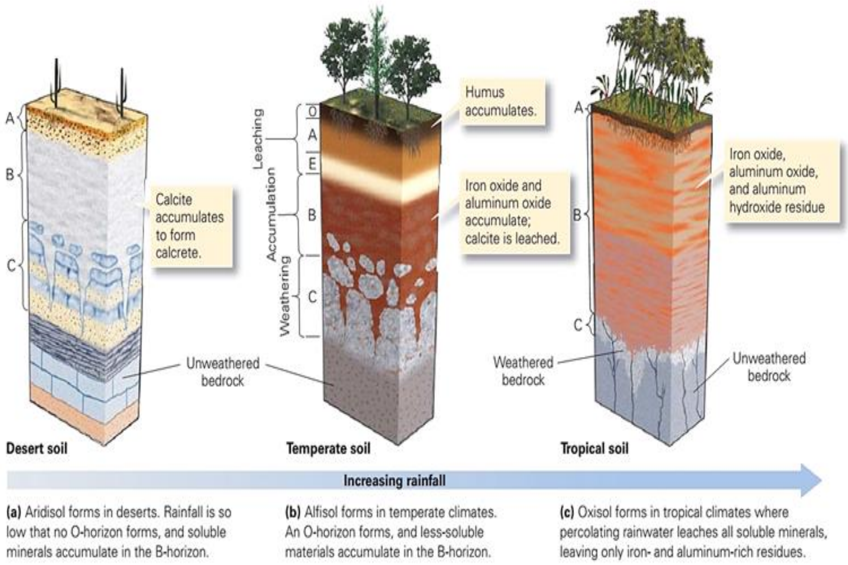

Figure 2. 8. Major Soil classification [64]

As can be seen in Figure 2.9. some of the soil engineering features with environmental factors illustrated like physical properties of soil such as permeability and the major difference between granular soils (gravel, sand) and fine soil (Silt, Clay).

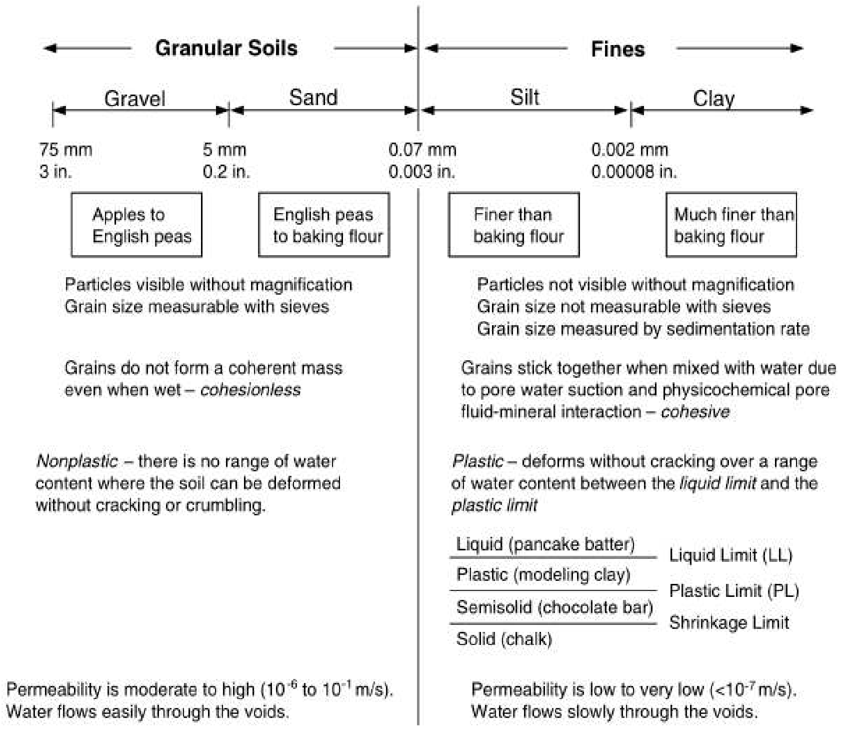

Figure 2. 9. Soil engineering features with environmental factors [66]

2.1. Earthquake Characterization

Herein some characterization of the earthquake has been explained. Also, some related studies have been highlighted.

Plate Tectonics of Earth: the continental crust is dense and old usually almost 40 to 50 km are thick [67]. And roughly 2×10^9 years old and covers almost 30–40% of the Earth's surface, and the remained amounts are oceanic crust [68]. The geometrical model of the earth's surface is considered to be made of 29 percent of Earth's surface with an average density of 2.8 for the oceanic crust and 2.7 for continental crust [66]. That has relative motion respect to each other, these transportations of crust to the Earth's topography [69, 70]. Called tectonic plates that this theory stayed as the first and only global geodynamic theory that governs all known tectonic phenomena, including seismic zones, mountain construction, structural characteristics, the nature of sedimentary basins, magmatism, and metamorphism, it is an elegant and complete synthesis of Earth's geodynamics [71]. Plate tectonics is the pattern that has been used for analysis the formation of Earth's crust and oceans, in particular, the principle of continents drift, earthquakes and many linked phenomena, continental drift was the theory in 1912 presented in two articles published by German meteorologist known as (Alfred Lothal Wegener), notwithstanding all plates have various small velocities, for example, our nail growth per year, but Pacific plate is the fastest plate in the hotspot reference system and dominates the net rotation of the lithosphere, it will because the move toward the west corresponding to the sub-asthenosphere mantle is faster perhaps modify between 50 and 90 mm/yr [72].

As can be seen from Figure 2.10. The split of the supercontinent (Pangaea) is a supercontinent containing all the continental crust of the earth (280-230 Ma) which seems to fit together by terrestrial fossils evidence. Alfred Wegener realized that have been the existence of matching (Permian-aged terrestrial fossils) in the various portion of continents such evidence for supporting his special theory [73]. The idea is not widespread, but new evidence suggests that the postulate is true. John Tuzo Wilson was the believed "continental drift" and formulated the theory of plate tectonics [74].

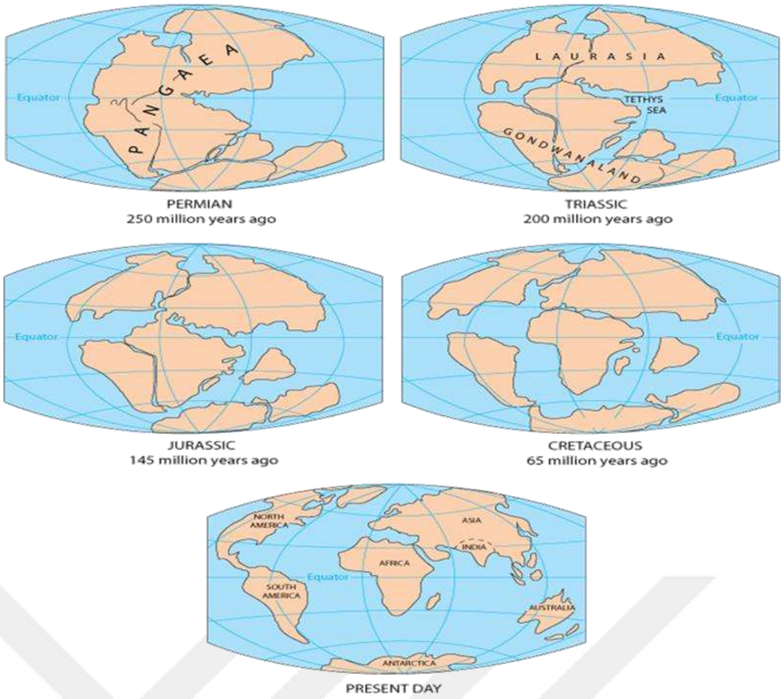

Figure 2. 10. The split of the supercontinent(Pangaea) [75]

The plate: is the ideal lithospheric region to rotate (relative to another specified plate) without any inner distortion around a conceptual axis that passes through the center of the globe [69].

Euler's rotation theorem: in spherical geometry, the relative motion of tectonic plates (earth's crust) on the (mantel) can be represented by this phenomenon [76].

Fault: Geologically fault would define as a fracture that appears during a violation of the continuity of rocks, without displacement (cracking) or by displacement of rocks along the fracture surface. Large faults in the Earth's crust are the result of tectonic plates altering their connections. This displacement perhaps a few millimeters to hundreds of meters. Inactive fault zones, earthquakes often occur as a result of energy being released during a rapid glide along the fault line. Because the faults are often appearance by the structural area of the same tectonic deformation associated with the fault plate, such areas are called "Fault Zones" Since a fault usually does not consist of a straight, regular groove and covers an area of complex deformation of the earth, they usually speak of a "Fault Zone," not a Fault [77].

There are three types of main Faults depends on the direction of slip

1- Strike-slip faults: also called (wrench) or (tear)or (transcurrent) The fault surface is usually near vertical with slight sidelong vertical movement, the footwall moves left or right [78, 79]. As can be seen in Figure 2.11.

• the normal fault: is the hanging wall goes to descend, relative to the footwall.

• the Graben*:* is the downthrown block placed between two extensional faults during move downward.

• the Horst: is the upthrown block placed between two extensional faults dipping away from each other.

1- Dip-slip faults: A fault can be both types of slips in extension or reverse.

2- Oblique-slip faults: or Diagonal-slip fault combining strike and dip slip [80].

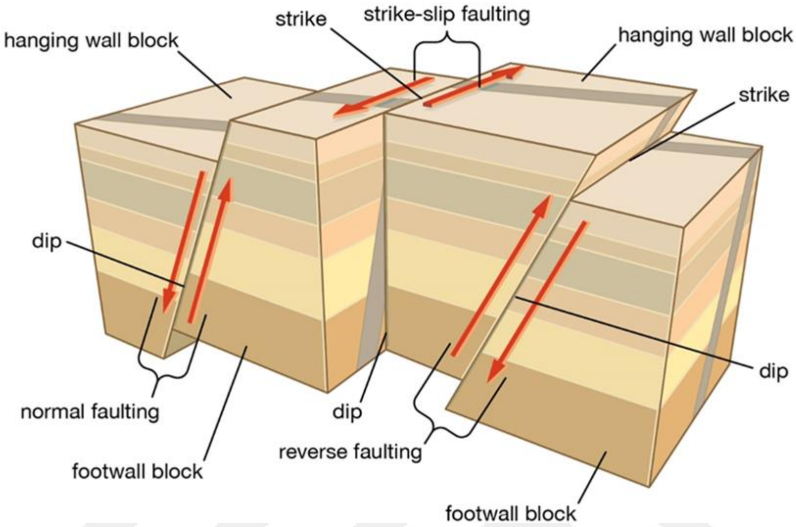

Figure 2. 11. Three foremost types of Faults [81]

On actual Earth, it is clear that any plate model is just a kind of estimation. earth's crust comprises the 14 largest plates, consisting of 95.1 percent of Earth's surface, And more than one hundred small plates that are not Easley can be observed from space by GPS [82]. the classical definition of plate tectonics is not performed in 15% of the surface of the earth by the shallow earthquake and active faults [83].

The key to understanding the concept of tectonic- plates mechanics, in brief, there are three main types of plate boundaries: Convergent boundaries, Divergent boundaries, and Transform Boundaries as can be seen in Table 2.1 and Figure 2.12.

Table 2. 1. The explanation of the main three types of plate boundaries [84]

Type of margin	Divergent(←→)	Convergent(→←)	Transform(↑↓)
Motion	Spreading	Subduction	Lateral sliding
Effect	Constructive (Oceanic lithosphere created)	Destructive (Oceanic lithosphere Destroyed)	Conservative (lithosphere neither created nor destroyed)
Topography	Ridge/Rift	Trench	No major effect
Volcanic activity?	Yes	Yes	No

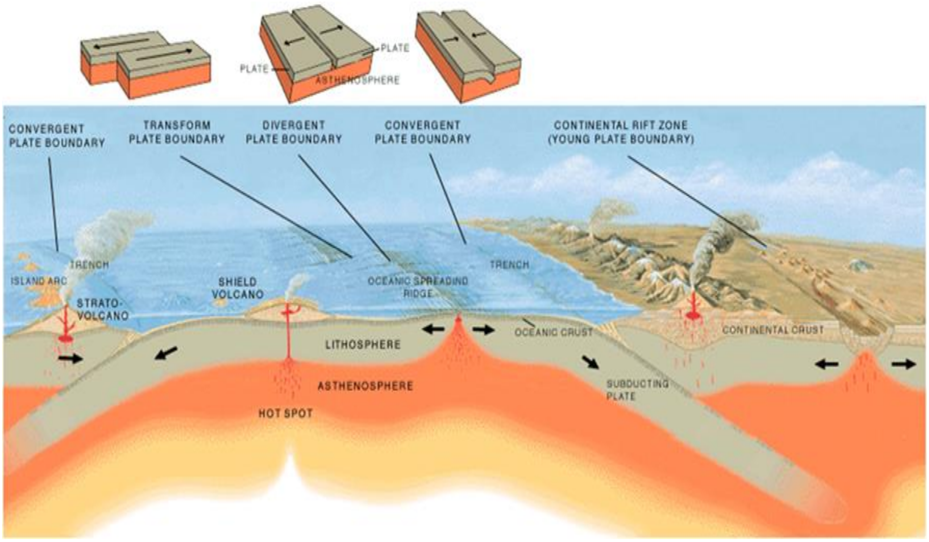

Figure 2. 12. Indications of tectonic plates type [84]

2.1.1. Pre-Earthquakes Predictions

The knowledge of the advance of geosciences and their experimental methods and theories in the past can improve our current understanding and may stimulate current research, pre-earthquake prediction needs to decipher the active behavior of the earth's layers inside of the earth and its Atmosphere, generally classified into three main groups due to the time scale estimated including, long, medium, and short term. the long -term covered between 10^2 to 10^3 years for an instant plate tectonic investigation and archeological survey, the medium-term as the crustal movement which bounded around 20 years ago, and the short-term which is the most reliable one which has the actual benefit because they can inform us a few days or hours before the major earthquake, due to rising abnormal changes in their received signals processes, such as the lithospheric effect, radon anomalous effect, Geomagnetic, Geoelectric, Ionosphere or pre-seismic change, thermal radiation anomalies, In entirety important variations in earthquake phenomena usually occur before the major earthquake which can be identified by the Amplitude and duration of anomalous change also by the spatial and temporal distribution of these changes observed beside the epicenters of the major shock, scientist's efforts to get credible prediction not stopped, similar sentences as shown in Figure 2.13. therefore, in 1999 by IUGG organization, (EMSEV) established that is a multidisciplinary team that contained from many international associations such as (IAGA), (IASPEI) and (IAVCEI), they are working on the (Electromagnetic Study of Earthquake and Volcanoes) Or (EMSEV) holds a congress every two years one time over the world and the next workshop will be held in Taiwan from 24 to 28 -August- 2020 [85].

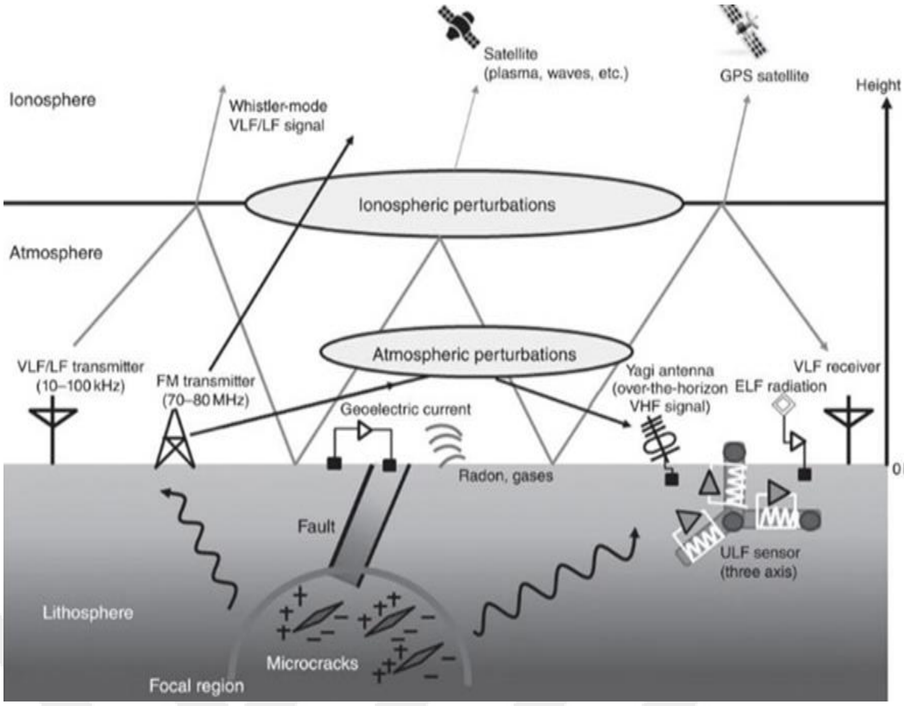

Figure 2. 13. Indicate short term methods for detecting subnormal signals from earth as a quake tracer [85]

2.1.2. Summary of Earthquake Concepts

Foreshock: is a weak tremor that occurs before the mainshock, as (micro- EQ) which does not happen systemically.

The main shock: is the earthquake with the biggest magnitude is considerably larger than other earthquakes in the series.

Aftershock: usually occurs after a large earthquake, which has a serious impact on a smaller scale than the main earthquakes, it continues for weeks, months, and years.

The hypocenter*:* is the focal point of earthquakes located under the epicenter that is the start point of the earthquake.

The deep focus of earthquake: four major depth ranges: With increasing focal depth (h) the maximum energy of a single shock decreases [86]. As can be seen from Figure 2.14. and Figure 2.15. Global seismic depth.

a. Shallow shocks depth: $h \leq 60$ km. in the crust
b. Intermediate (Deep) shocks: $60 < h \leq 300$ km in the (lithosphere) and (Asthenosphere)
c. . Deep shocks: 500 km $> h > 300$ km. in the (Asthenosphere)
d. Very deep shocks: $h > 500$ km. located in the lower mantle (mesosphere)

The epicenter: is the location on the surface directly above the earthquake's focus.

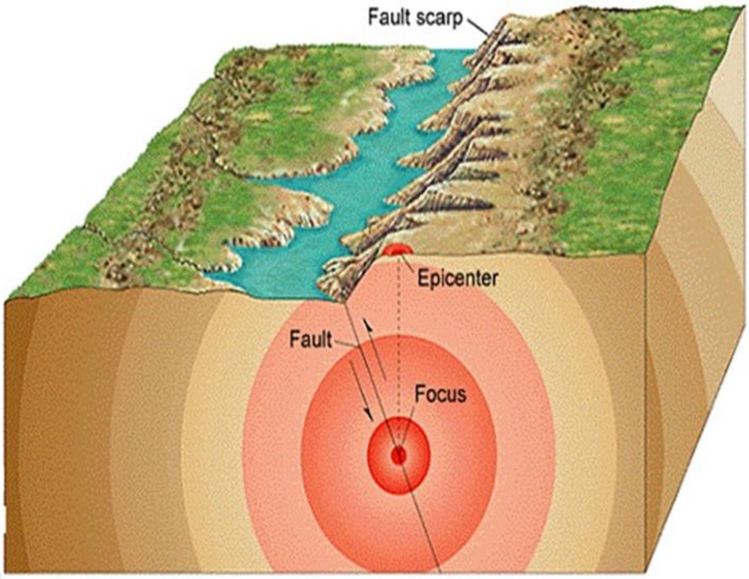

Figure 2. 14. Focus point (hypocenter) and Epicenter of the earthquake [75]

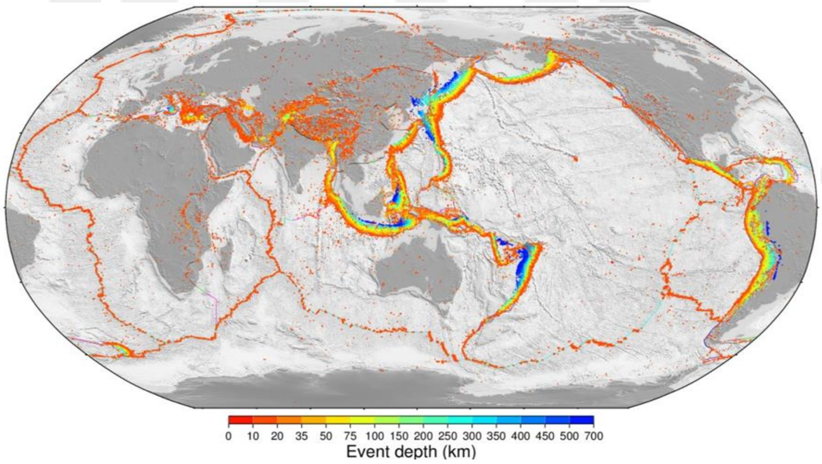

Figure 2. 15. Global map of earthquake's depth, ISC-EHB locations color-coded by depth [87]

2.1.3. Types of Seismic Waves

Earthquakes generate seismic energy as both body and surface waves, Body waves arrive before the surface waves emitted by an earthquake as can be seen from Figure 2.16.

1- Body waves: are unique waves made by seismic activities that can travel in the lithosphere. These waves are of a higher frequency than surface waves. There are two types of body waves. These contrast with surface waves [88].

   a. (primary waves or pressure wave) or (P waves):

It is longitudinal wave travel approximately half times faster than S-waves, therefore, named primary wave because it is the first wave arriving from an earthquake is always a compressional wave. And can be reached and refracted in the outer core (liquid core) of the inside (center)the earth.

b. (secondary waves or share wave) or (S-waves):

They are transverse waves. However, it is slower but more destructive than P-wave, this wave can only move through solid materials because these rocks have enough shear strength. S-waves need a medium that is rigid enough for them to propagate and Liquids lack shear strength, this is why S-waves cannot propagate through liquids or the liquid core of the earth.

2- Surface waves or Love Waves and Rayleigh wave:

Surface waves: Generated by a great earthquake and very dangerous insomuch it tends to move forward, backward, left and right the surface of the earth. illustrates the Global Seismic Hazard Map by S- waves, Given in Figure 2.17.

Rayleigh wave: It collects P with S-Wave. The surface vibrates forward and backward in the direction of the wave is as well as vibrate up and down perpendicular to the direction of the wave. A surface moving in a vertical circular path, The Rayleigh wave is extremely damaging because particle direction moves in two directions at once.

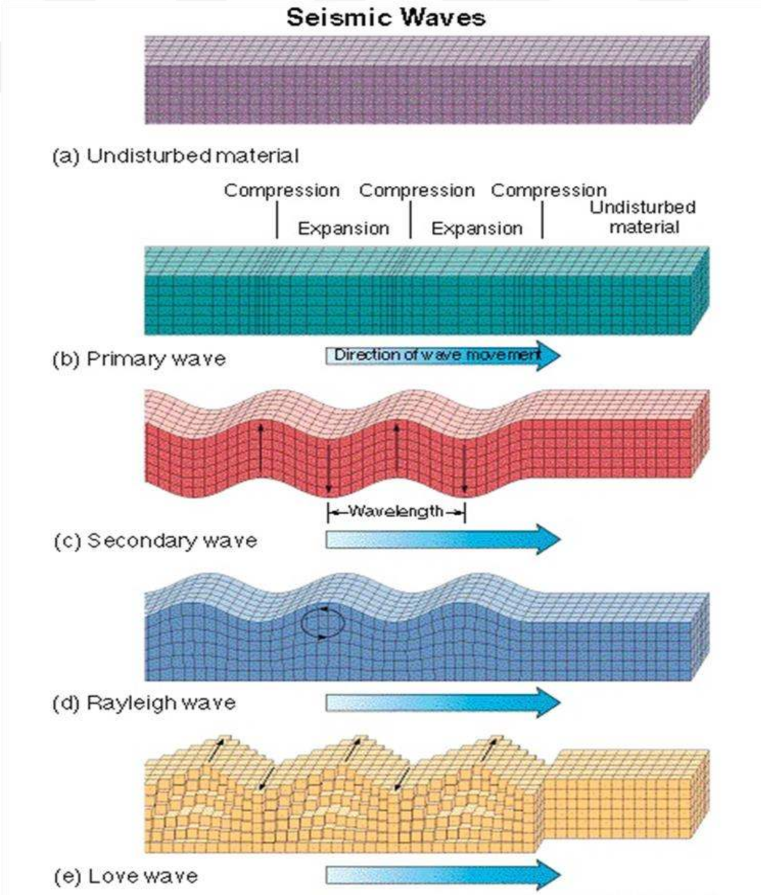

Figure 2. 16. Types of seismic waves [89]

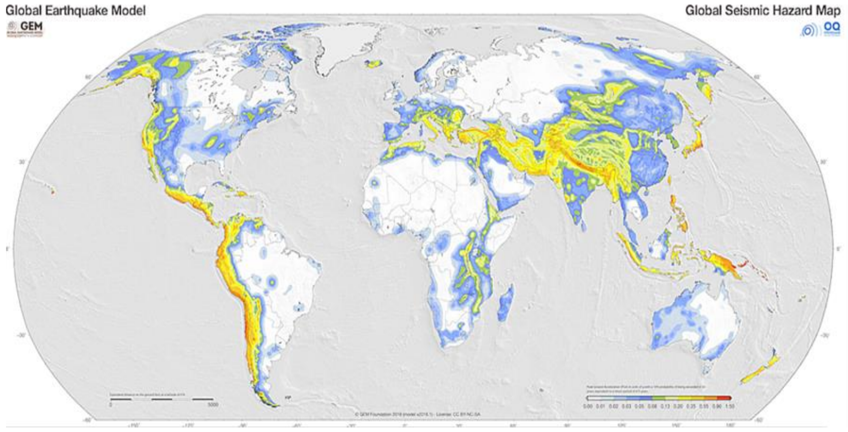

Figure 2. 17. Global Seismic Hazard Map (GEM) [75]

This map is designed by compiling maps calculated using national and regional seismic hazard models developed by various GEM institutions, projects, and scientists [90].

2.1.4. Convection in the Earth's Mantle

the thermo-rheological pattern for tending to compress lithosphere metamorphosis, energy current need exceed 75 mW m^{-2} [90]. Many geophysical and geochemical studies regarding convection in the earth's mantle and the dynamics of the tectonic plates are presented [91]. Plate tectonic theory wealthy considered seriously of international volcanism and seismicity [92]. The mantle is cooled primarily by the sequence of plate construction and subduction [93]. It was prominent that some volcanoes, frequently faraway from plate boundaries, had not been shaped by the same procedures [94, 95]. The principal method of cooling the mantle is the cycle of plate generation, chilling, subduction, and heating again. Leastways 85 percent of the heat released from the inside of the earth is allocated to this mechanism [91]. Morgan suggested that the source of such hot spots is the deep mantle plumes generated in the undermost mantle, they are the most well-known extinct volcanoes, which are believed to have shaped on the lithospheric layer because the plates move above them. Hawaii and its associated Hawaiian Ruler seamount chain are the most notable[96]. As can be seen from Figure 2.18. It defined the sources of the three varieties of plumes hotspots: the primary, deeper plumes likely arising from the lowest mantle barrier layer, the ‘secondary’ plumes mayhap getting from the top of vaults near the depth of the transition region at the sections of the super inflation, are pointed [97, 98]. The "third" hotspots may have a surface area, which is eliminated by tensile stresses in the lithosphere and pressure melts [99].

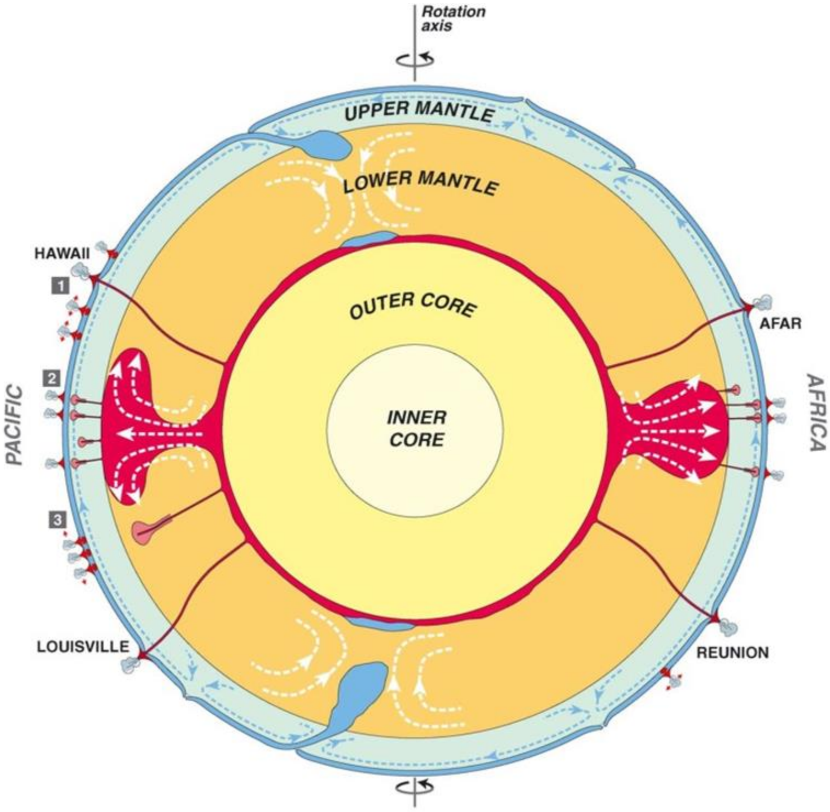

Figure 2. 18. Defined the sources of the three varieties of plumes hotspots [100]

2.1.5. Earthquake Measurement

Apart from the various shortcomings, the large scale of earthquakes is one of the major causes of seismic resources used in the lists, although it is desirable to use the unit scale, this is not always possible due to changes in measuring equipment, data reduction methods, magnitude formulas, station distribution, and so on, the use of large scales set in different periods provides a good way of describing earthquakes.

There are Several measures are specified, but the most common are

1- Local magnitude (M_L), called the Richter scale,

2- the magnitude of Surface waves (M_s),

3- Body-Wave magnitude (M_b)

4- the moment magnitude (M_w) [101].

Scales 1 to 3 have a limited scope and cannot adequately measure the magnitude of a strong earthquake. The moment magnitude (Mw), based on the concept of seismic moment, also applies to all seismic measurements, but its calculation is more difficult than for other species. All size measurements should give approximately the same value for any earthquake, the (Mw) can be used to quantify non-deep and deep earthquakes based on the energy of the emitted waves to provides a uniform scheme [102]. The biggest earthquake ever measured on World got 9.5 M and bring out 570 casualties in Chile on the 22nd of May in 1960 [45].

Seismograph: The strength of an earthquake can be measured by a device called a seismograph.

The Mercalli scale: relating the severity of EQ, since the 19th century used for an estimate the intensity of the earthquake which impacts on the earth's surface It uses values from I to XII, less advantageous than the Richter scale, because of its subjectivity compared to the objectivity of the Richter scale.

Richter scale: was developed in 1935 by Charles F. Richter, in public, the Richter scale is more universally used than the Mercalli scale, which is mainly based on objective reports of loss and destruction. Based on the size of the seismograph oscillations as can be seen from Table 2.2.

Table 2. 2. Correlation between Richter scale magnitude, Mercalli' scale, and output energy [103]

Mercalli'scale Intensity class	Magnitude in Richter Scale	Energy generated in Joules	Exemplification
I, II, III, IV	2.0	1.3×10^{8}	Lowest EQ which humans can feel indoor
V, VI, VII	5.0	2.8×10^{12}	The energy released by the atomic bomb in Hiroshima, people frightened and run to outdoor. A small crack will appear on the wall.
VIII, IX	6.0 - 6.9	7.6×10^{13} to 1.5×10^{15}	Approximately 120 shallow EQ of this magnitude happens annually on the globe. large cracks in walls displaying
IX	6.7	7.7×10^{14}	California, Northridge EQ 17th of January in 1994. General panic, Lots of feeble buildings collapse.
X	7.0	2.1×10^{15}	Great EQ threshold. ordinary well-built buildings collapse
XI	7.4	7.9×10^{15}	Turkey EQ 17th of August in 1999. Over twenty thousand persons killed. Most ordinary well-built buildings collapse
XI	7.6	1.5×10^{16}	Fatal EQ in the last Century. Tangshan, China,28th of July in 1976. Almost 255 thousand persons perished.
XII	8.3	1.6×10^{17}	Virtually all buildings are destroyed SF seismic activity, 18th of April in 1906.
	9.3	4.3×10^{18}	26th of December in 2004 Sumatra seismic tremor.
	9.5	8.3×10^{18}	The most influential tremor noted in the previous Century. Southern Chile on May 22, 1960. Claimed 3000 lives.

2.1.6. Earthquake in Turkey

Earthquake accounts for 6,8 % of the natural disasters which is the greatest amount of death and injured Natural catastrophes in Turkey from 1900 to 2018, that earthquakes events during the last century were responsible for 95,6% of death and 77.2% of injured [104]. To date, the largest earthquake in Turkish history has gained a magnitude of 8.0 points, hitting Antakya and leaving 250,000 dead. The event most likely occurred on May 20-29, 526 AD [105].

In 1970 and 1971 with M= 7 largest earthquakes in the Himalaya belt, generally, all earthquakes in turkey are shallow [106].

Turkey is located in the Eastern Mediterranean confines of the Alpine-Himalayan orogenic system [107]. With contemporary faults and dynamic volcanism which is the cause for Turkey’s rich geothermal stocks [108]. It’s one of the regions with the highest seismic activity in the world. The description of seismic zones of prim in this region necessitates the assessment and integration of geological, geophysical, seismological, and geodetic data [109].

Through the study of Turkey's seism, tectonic background described one of the major distorting regions of the world. Tectonics surround Turkey be influenced by relative movements between the African, Aegean, Arabian, Anatolian, and Eurasian plates. As a result of turkey’s strategy has plenty of risky located among several geotectonic, Turkey is categorized by difficult geology [110]. And is divided into three foremost tectonic units: the Pontides, Anatolide–Tauride, and Arabian platform [111].

The descending mobility of the edge of the African plate to the beneath of the Aegean arc and Cyprian arc provides a complicated tectonic process containing a backward traction dominion in Western Anatolia [112]. As can be seen from Figure 2.20. the recently completed in 2013 as can be seen in Figure 2.19. and the named it the active Faults map of Turkey [107].

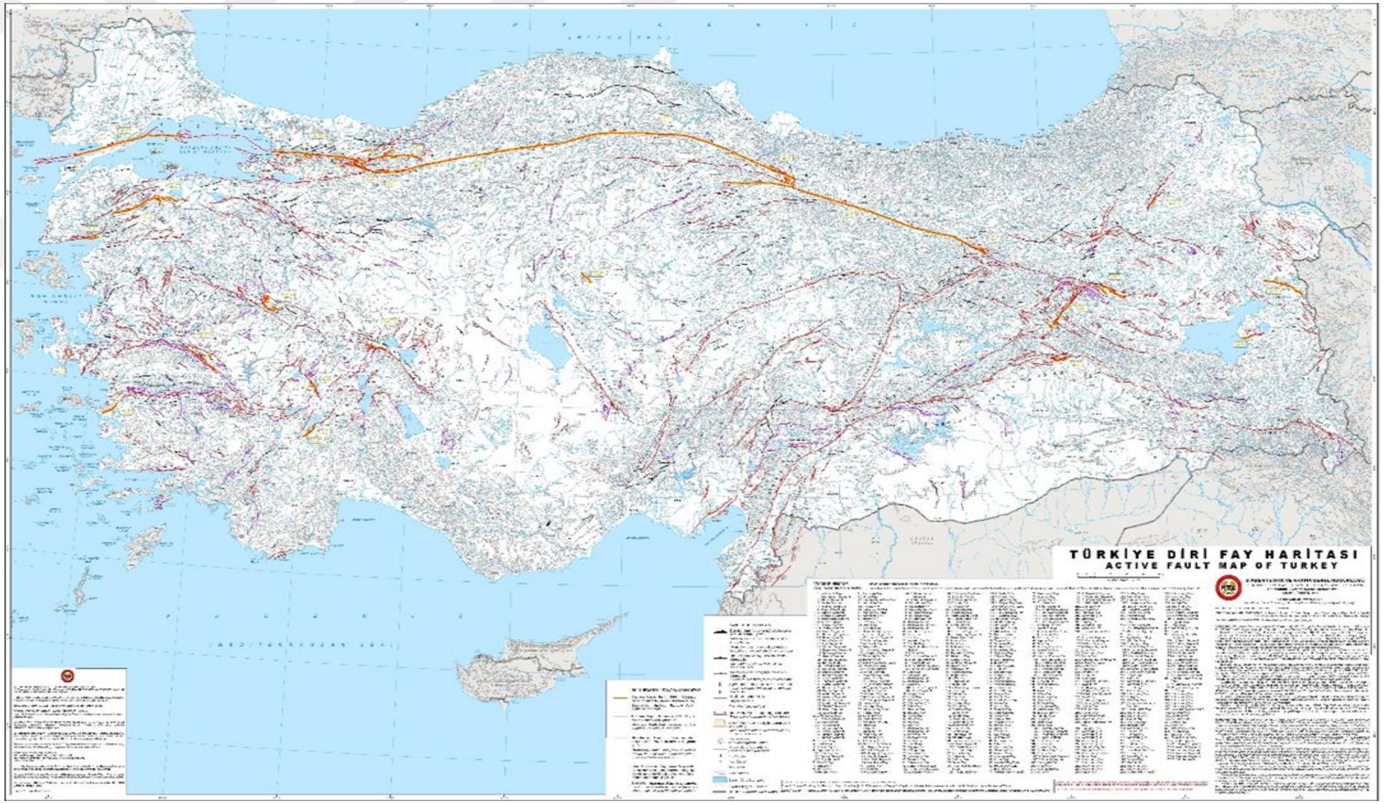

Figure 2. 19. The Complete Active Fault map of Turkey,1:1 250 000 Scale [113]

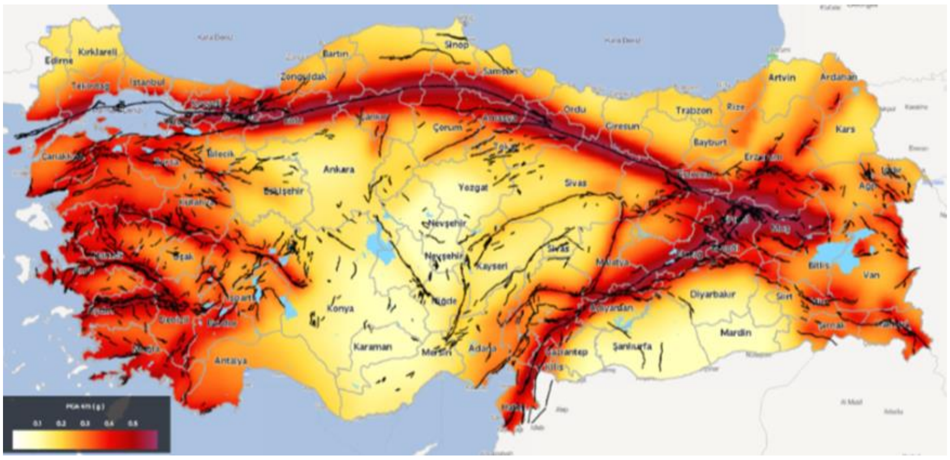

Figure 2. 20. Earthquake Hazard Map of Turkey [114]

Tectonics regime in turkey involved, North Anatolian Fault Zone (NAFZ), south East Anatolia Fault Zone (SEAFZ), and West Anatolia Fault Region have a look at the Turkey hazard map that shows the most common Faults in black and red color lines, as can be seen from Figure 3.11. It is the updated hazard map of turkey subsequently twenty years, the most common seismic resource sections are described in the history of turkey derived from the maximum earthquake was determined for each seismic zone [115].

Earthquake in Erzincan

History of biggest Earthquake in Erzincan and the horrendous disaster in the last century was the Earthquake on 26 to 27 December 1939, see Figure 3.13., by M= 7.9, Erzincan province which locates in northeastern Turkey destroyed and had heavily damaged such as many consequences surface cracks, landslides, tsunamis in the Black Sea, as well as the destruction of buildings and over 30,000 people lost their lives and 17500 people were injured. it had been affected eleven cities around itself [116-117]. After this earthquake, Erzincan relocated position and rebuilt in a new location [118]. After an earthquake that created 360 km translocated in that area. Traces of this surface rupture are still visible [119].

Besides, the second largest earthquake in Erzincan occurred on March 13, 1992, M = 6.9 in the Richter scale aftershock sequence[120]. And devastated a section of the North Anatolian Fault (NAF) on the northern border of the Erzincan Basin, Or in the eastward mid-part of the Erzincan.

Basin, the focal depth of approximately 10 km was less than that indicated by ISC and NEIC [121]. This event occurred at the eastern end of a series of large North Atlantic earthquakes extending west from 1939 to 1967 [122]. The consequences of the deaths in the city were 538 people, 850 of whom were injured and hospitalized [123].

Geophysics of the Erzincan

Eastern Turkey is in complex tectonic movements as can be seen from Figure 2.21. Is located in a converging north-south zone between the Eurasian plate to the north and the Arab plate to the south. Between these two plates, there is an Anatolian microplate which, due to the north-south compression is forced to move west along two main slip faults, namely the North Anatolia fault (NAF) and the Eastern Anatolia fault (EAF) [124].

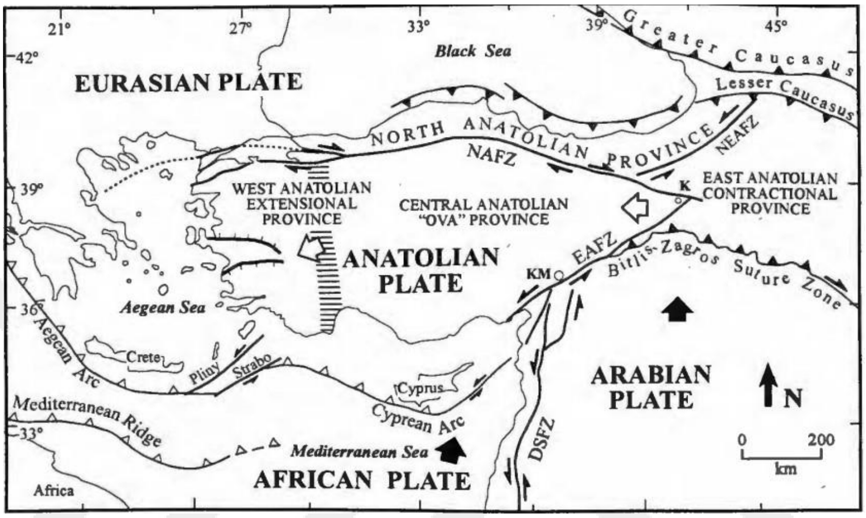

Figure 2. 21. Turkey influenced under various tectonics displacement illustrated by arrows [111]

The Erzincan is one of the provinces of Turkey placed in the northeastern side of this country, that is on the Northeast Anatolian fault zone (NAFZ) although, at an altitude of nearly 1185 m over the sea level, the location of this city indicated by the latitudes and longitudes of 39º 02′–40º 45′ N and 38 16′–40º 45′ E Respectively, Erzincan area is approximately 12,000 km^2 and concerning its population about 220,000 persons as of 2013, that estimated to be 235,000 in 2020. It has chilly winters and hot summers, in the Erzincan basin, there is a fault system producing earthquakes. Of the seven violent earthquake shocks [125].

Common Geology of Erzincan Basin

The Erzincan Basin is the largest of several strike-slip basins that were formed along the NAFZ in the pre-Pliocene basement on the edge of the Eurasian and Anatolian plates [126]. The basement separated in two blocks North and South, the southern block contains Permian to Cretaceous limestone which is under the cover of indescribable Paleozoic metamorphic rocks containing gneiss and muscovite-quartz-calc schists, the northern block includes Permo-Triassic metamorphic rocks, Liassic-Dogger volcano-sedimentary rocks, and Upper Jurassic-Cretaceous limestone, marl, and clay, as can be seen from Figure 2.22, and for Erzincan Lithology given in Figure 2.23.

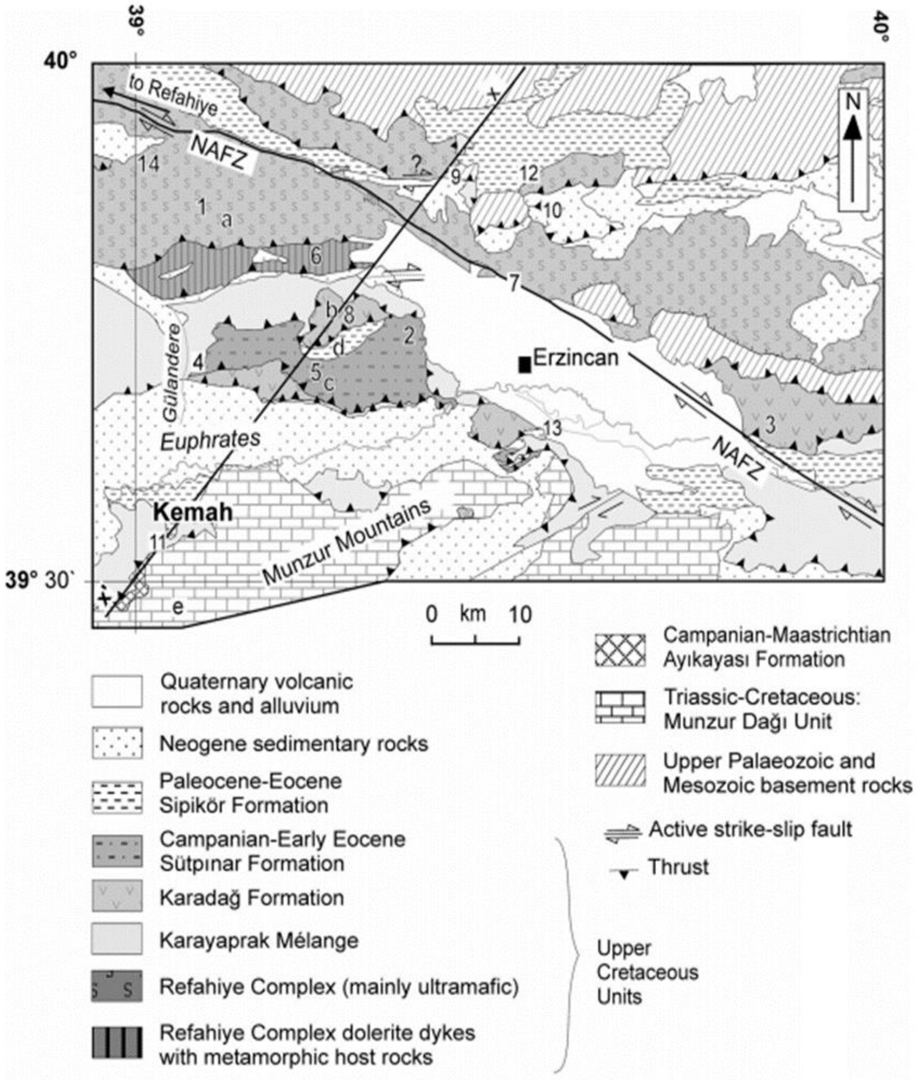

Figure 2. 22. Simplified Geological map of the Study area (Erzincan) [127]

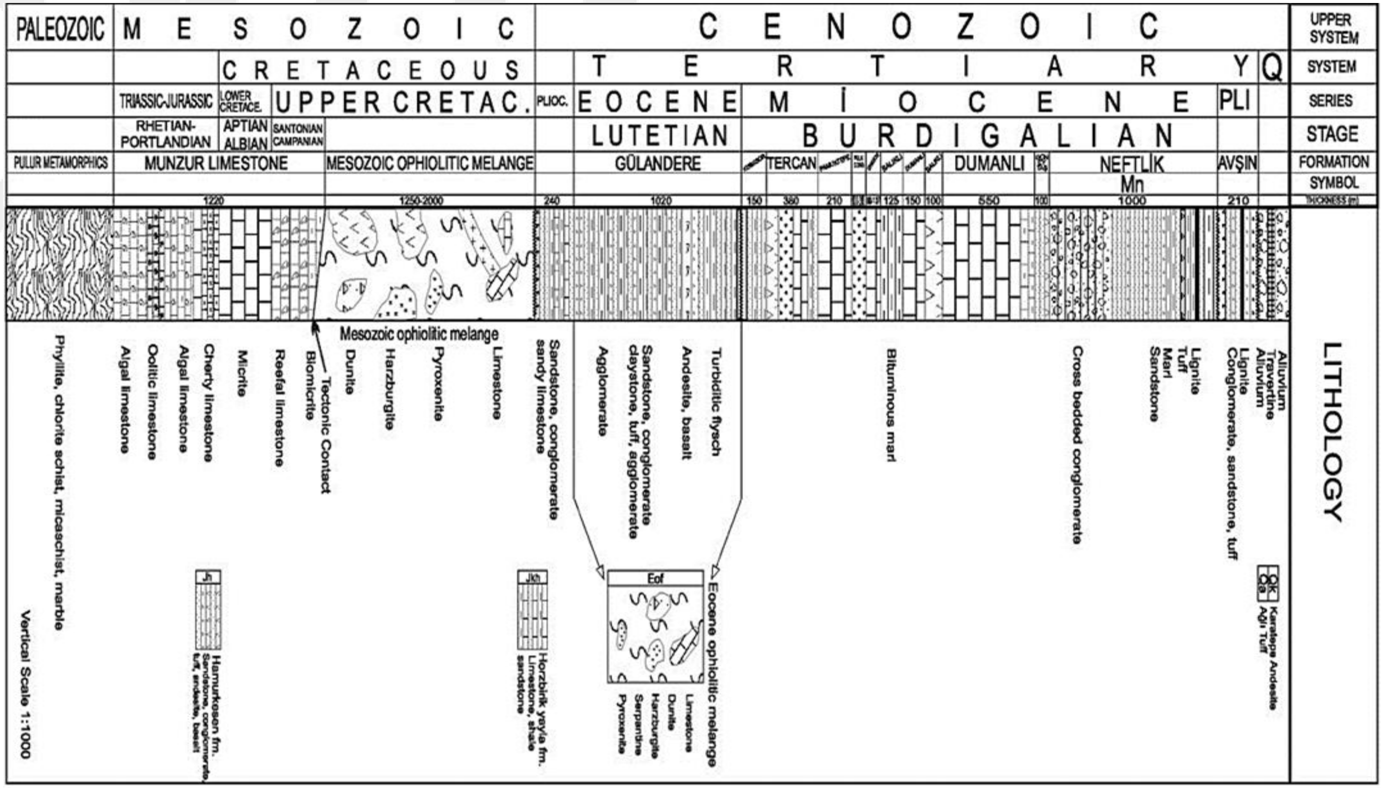

Figure 2. 23. Generalized columnar section of the Erzincan region [128]

2.2. Radioactivity

Radioactivity discovery was the start of nuclear science [129]. Soon after the discovery of X-rays in 1895 by Wilhelm Conrad Roentgen, the history of radioactivity started in Paris in 1896 during since Henri Becquerel realized the sensed radiation-emitting by uranium after seeing the darkening of a photographic plate in touch with uranium crystals in his laboratory, and in 1903 was granted half of the prize for his discovery of spontaneous radioactivity, he was supervisor of Marie Curie (1867-1934) polish scientist who was the first-ever woman that granted Nobel prize in both fields (physics 1903 and chemistry 1911) in the last century, she discovered new radioactive element polonium and Radium with her husband's partnership Pierre curie in 1898. they excited by Becquerel's discovery and Marie and Pierre Curie were granted half the Nobel prize in physics 1903 for their investigation on the radiation phenomena discovered by Becquerel, Marie Curie discovered the radiation of all compounds containing the known radioactive elements, including uranium and thorium, she proofs that radium is the heaviest alkaline earth element. additionally, discovered that the strength of the radiation from uranium can be exactly measuring and the intensity of the radiation is proportional to the quantity of uranium or thorium in the compound, regardless the type of its compound, and the capability to emit radiation does not depend on the arrangement of the atoms in a molecule, it necessity be united to the inside of the atom itself, it was a revolutionary discovery [75, 129-133]. The radioactivity discovered by the three famous scientists as can be seen in Figure 2.24.

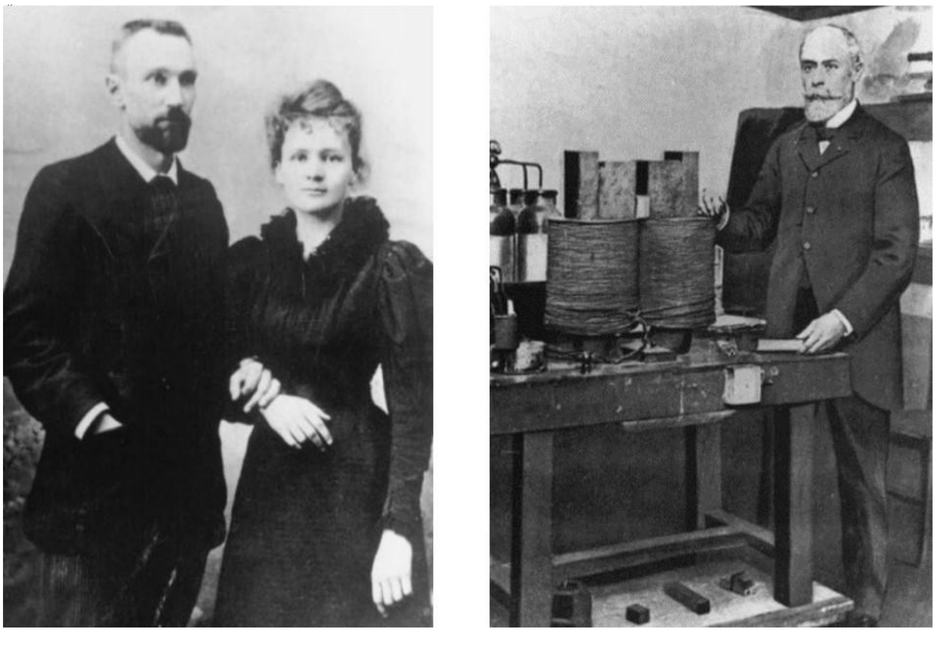

Figure 2. 24. Maria Sklodowska and Pierre Curie 1895 marriage date and Henry Becquerel in his lab [131]

2.2.1. Radioactive Nuclides in the Environment

Three-fourths of radioactivity produced naturally in the earth[9]. that generally emanates from the environment in two main sources, (i) the decay of radioelements or radioisotopes in the soil and bedrocks (ii)cosmic radiation, when the Earth formed 4.5 Ga, the huge amount of radioactive substances had been generated at that time, and short half-lives isotopes exist lesser than very long half-lives isotopes in the earth [134]. Among them are three main uranium isotopes [^{238}U (99.27%), ^{234}U (0.006%), and ^{235}U (0.72%)] atom percent [135, 136]. With natural rocks holding uranium densities ranging from 0.5 to 5 ppm [137]. Then unstable isotopes will naturally undertake various decay series of radioactive emissions by alpha and beta and gamma radiation finally they will decay to one type of Pb (is one of the three pillars of lithophaile isotopes geology) [31]. many other unstable isotopes have a long half-life. The most important of certain is ^{40}K, ^{232}Th. Many short-lived isotopes are also seen in nature that might be derived from long-term isotopes, or by cosmic rays, radioactivity is a process involving events in individual atoms and nuclei. Before discussing radioactivity, therefore, it is useful to review some of the basic concepts of atomic and nuclear physics, one part of the universe is governed by radioactivity, the structure of the universe mostly consists of unstable elements, and by the efforts of scientists in the last century they figured out that except hydrogen, all nucleus in atoms in nature comprises neutrons and protons. The ratio between them is the unity for Lightweight isotopes that are called the "stability line" and progressively together until going on the “stability line, this ratio will rise extent until nuclide changed to unstable. Accurately after ($^{209}_{83}Bi$) nuclides are unstable for the reason that they have a huge amount of energy to disintegrate their nuclei, similar nuclei are known as radionuclides which their excess energy by the radiation will be releasing, this procedure is known as radioactivity decay, the decomposition of a radionuclide is a numerical procedure, therefore, the prediction will be impossible at what time an individual nucleus split, while has a possibility for a nucleus will decay in unit time, this likelihood is called the radioactive decay constant (transformation constant), λ of the radionuclide, the number of atoms in the emitting radiation element decaying per unit time, A= dN/dt, (A) will be denoted the activity of the material, is the sign of the sum of numbers, N, of radioactive atoms in progress at a time (t), the continuous of proportionality presence λ, the units of λ are 1/s (so that the quantity λ t in the exponential is unitless).

$$- dN/dt = \lambda N \tag{2.1}$$

by integrating the above equation

$$-\frac{dN}{dt} = \lambda N \quad \rightarrow \quad \frac{dN}{N} = -\lambda\, dt \quad \rightarrow \quad \int \frac{dN}{N} = -\int \lambda\, dt \quad \rightarrow \quad \int \frac{dN}{N} = -\lambda \int dt$$

$$\ln N = -\lambda t + C \quad \rightarrow \quad (\ln N = -\lambda t + C)\, e \quad \rightarrow \quad N = e^{-\lambda t + C}$$

when $t = 0$ $\quad e^{c} = e^{0} = constant = N_{\circ}$ then we can change to $\quad N = e^{-\lambda t} . N_{\circ}$ or

$$N = N_{\circ} . e^{-\lambda t} \qquad (2.2)$$

where $N_{\circ}$ is the original number of radioactive atoms present, and N, as already stated, the number of radioactive atoms at the time (t), rewriting equation. (2.1), it follows that

$$-\frac{dN}{dt} = \lambda N = N_o\, e^{-\lambda t} \qquad (2.3)$$

Equations (2.2) and (2.3) indicates that the number of radioactive atoms present as well as the Disintegration rate (activity) decreases exponentially with time, the time taken for half the radioactive atoms originally present to decay is called the half-life of the radionuclide, Substituting $\frac{N_o}{2}$ and t = $t_{1/2}$, in equation (2.2), one obtains

$$\frac{N_{\circ}}{2} = N_o\, e^{-\lambda t_{1/2}} \quad \rightarrow \quad \left(\frac{N_o}{2} = N_o\, e^{-\lambda t_{1/2}}\right) \div N_o$$

$$\frac{1}{2} = e^{-\lambda t_{1/2}} \qquad (2.4)$$

or

$$\left(2 = e^{\lambda t_{1/2}}\right) \times \ln \quad \rightarrow \quad ln\ 2 = \lambda t_{1/2}$$

$$\lambda t_{1/2} = \ln 2 = 0.693 \qquad (2.5)$$

or

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} \qquad (2.6)$$

where $t_{1/2}$ is the half-life, there is also a relationship between half-life ($t_{1/2}$) and the decay constant (λ) [138]. The number of nuclei present as a function of time given in Figure 2.25.

The normalized probability density function for the observation of decay after a time (t) is:

$$f(t) = \lambda e^{-\lambda t}\, dt \qquad (2.7)$$

The average decay time of isotope is given by:

$$\tau = \langle t \rangle = \int_0^{\infty} t\, \lambda^{e^{-\lambda t}}\, dt = \frac{1}{\lambda} \qquad (2.8)$$

The decay law can, therefore, be written as

$$N(t) = N_{\circ}\, e^{-\frac{t}{\tau}} \tag{2.9}$$

In nuclear physics, it's customary to characterize a decay by its (half-life) $t_{1/2}$ rather than by the average decay time τ .and τ is the mean lifetime [139].

$$\frac{1}{2} = e^{\frac{t_{1/2}}{\tau}} \tag{2.10}$$

$$t_{1/2} = \tau\, lin\, 2 \tag{2.11}$$

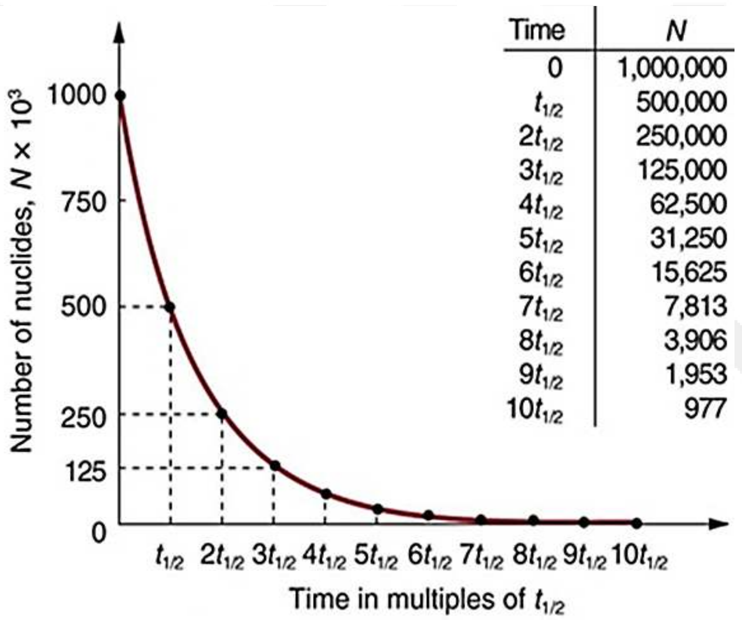

Figure 2. 25. The number of nuclei present as a function of time [140]

2.2.2. Units for Measurement of Radioactivity

The first scientist who used the term radioactivity was famous polish-born scientist Maria Sklodoska - Curie (1867-1934), after few years of the finding of this fact by Henry Becquerel in 1896, indeed, the name of both scientists well known with radioactivity the (SI) unit of activity was unit one recently Ci (curie) now changed by Bq (Becquerel) constant [141]. One (Bq) is defined as one disintegration per second (dps), the curie is defined as 3.7×10^{10} dps, so (1 curie (Ci) = 3.7×10^{10} Bq). The most commonly used units are the mCi and the µCi.

- Gray (Gy): To determine the magnitude of absorbed dose needs to notice the quantity of energy verily absorbed by several materials which consuming for every radiation or material (undescribed the biological factors of various radiations) Gy= J/Kg

- Sievert (Sv): To obtain an equivalent dose. the absorbed dose in man tissues to the impressible biological impairment of the radiation. Sv = Gy ×Q (Q = Quality factor unique in incident radiation)
- Rontgen (R): unit of exposure but merely for γ –ray or x-rays, as well as in the air. (R= sufficient stored energy in the dry air to make 2.58×10^{-4} C/kg, while (C = coulombs)
- Rad (radiation absorbed dose): to get the amount of absorbed dose 1 rad = 0.01 J/kg = 0.01 Gy.
- Rem (Roentgen equivalent man): to obtain the equivalent dose link the absorbed dose in man's tissue to the efficacious biological harm of radiation [142].

Units of measurements in SI units and common radioactivity units are given in Table.2.3.

Table 2. 3. Units of measurements SI units and common radioactivity units [142]

	Radioactivity	**Absorbed Dose**	**Dose Equivalent**	**Exposure**
Common Units	Currie (Ci)	RAD	REM	Rontgen (R)
SI Units Units	Becquerel (Bq)	Gray (Gy)	Seivert (Sv)	Coulomb/Kilogram (C/Kg)

The RCs measuring by capturing the alpha generated in its decay. Each alpha counted implies an Rn decay, hence RCs are measured in Bq or d/s the concentration of radiation in the atmosphere, water, and surficial soil air measured in Bq/m^3. For radon isotopes concentration unit or all radionuclide activity in air is normally used pCi/L or Bq/m^3, 1 pCi/L = 37 Bq/m3 = 2.22 d/min [143].

2.2.3. Basic Nuclear Transformation

Every unstable radionuclide undergoing one of the following basic nuclear transformations: α(alpha) decay, -β (beta minus) decay, +β (beta plus) decay, or beta electron capture, and γ (Gamma) decay [144]. There are six basically unlike types of nuclear decay reactions, and each release distinct particle or energy, the essential features of each reaction are given in Figure 2.26. the furthermost public is alpha and beta decay and gamma emission, but the others are essential to an understanding of nuclear decay reactions.

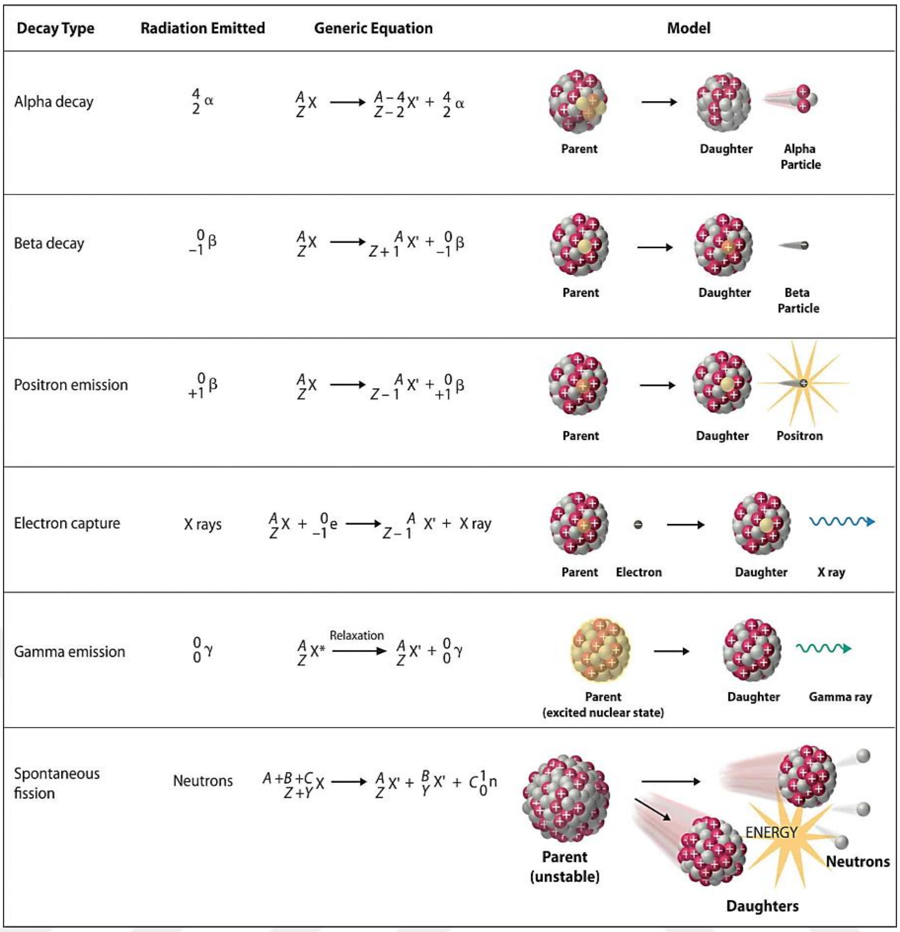

Figure 2. 26. Common Methods of Nuclear Decay [145]

The comparison between three types of radiation that occur during the radionuclide decay chain given in Table 2.4.

Table 2. 4. Properties of nuclear radiations [145]

Radiation	Ionizing Power	Range in Air	Stopped by	Effect of Electric and Magnetic Field
Alpha	strong	A few centimeters	Paper or thin card	Very small deflection
(β)Beta	Moderate	About 1 meter	5 mm of Aluminum	Large deflection (in the opposite direction to alpha)
(γ)Gamma	Very weak	At least 1 km	About 10 cm of lead	None

Unstable atoms are radioactive nuclides, the graph as can be seen in Figure 2.27. shows the ratio between neutron-to-proton for steady nuclides with different kinds of radiation, there are 264 stable nuclides discovered in the environment these nuclides are identified as the band of stability, and the changes they experience to reach stability are called radioactive decay, the limit of the band of stability ending at 83 protons (Bismuth). All the nucleus which have greater than 83 protons are radioactive, but scientists have claimed that there ought to an insignificant island of constancy nearby the point representing 114 protons and 184 neutrons, the relative stability of the densest atoms that have been made in the research laboratory proposed that this is correct [146].

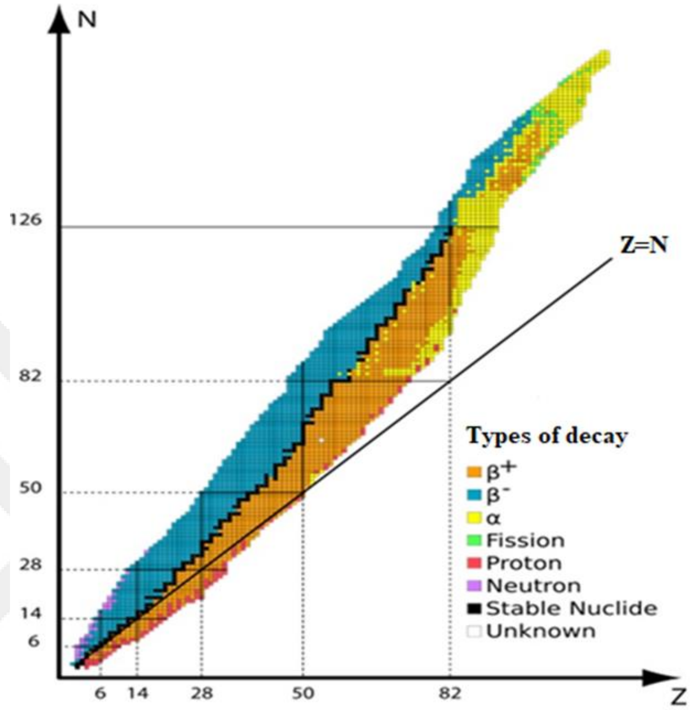

Figure 2. 27. The line of stability [103]

The most traditional and still prevalent techniques use the radioactive decay itself. All apply methods for catching the ionizing particles delivered while radioactive decay, these " activities,'' the number of atoms that being decay per unit time, is considered to use the numbers of atoms decaying per (g or cm^3) of sample and time, which is called ''specific activity''. Ordinarily, just not essential, these techniques are trained in the forms of radioactivity (alpha, beta, gamma radiation), and all accepted specific characteristics of the radiation, like the sort of radiation or particle energy. The aforementioned process of lab methods is named as Radiometry[147].

In the Atom's nucleus, as can be seen in Figure 2.28. the number of the proton is equal to the number of electrons for all atoms which isn't ion but neutron's number can be the main reason to product isotopes of atoms the ratio of neutrons to protons is the unity of lighter isotopes which is named "stability -line" and slowly obtained the behavior of elements which is located at the bottom of the periodic table, nuclide will be unstable at this stage [16].

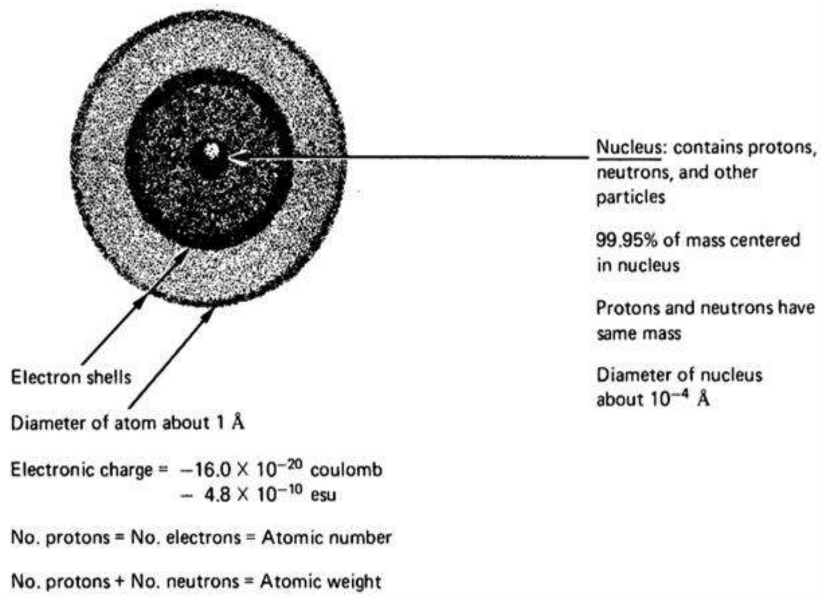

Figure 2. 28. A simple diagram of an atom [66]

2.3. Natural Radiation by Terrestrial Effects

In this chapter, natural radiation especially radon gas has been expressed. In 1901 Rutherford and Brooks confirm that radon is a radioactive gas and in 1903 he noticed that radon is very condensable at low temperatures, in 1951, Rochester University investigators noted that the risk of lung cancer was related to the dose of alpha particle emission from the radon gas decay production [148]. Radon exists in a variety of soils in the lithosphere, RCs in soil depends on the attendance of the original resources, ^{238}U, ^{234}Th, ^{230}Th, ^{234}Pa and ^{226}Ra, and so on, but the radon migration in the environment depended on some influential characteristics such as meteorological with Seasonal and spatial trend, geophysical, geochemistry of the research area that is why radon discharges are often observed in volcanically and tectonically active areas to determining alterations in soil gas concentration, as a result of the specialty of radon gas, it used in many acts as a tracer for quakes forecast. And reveal hidden active faults, seismic activity inactive faults can be predicted with positive radon gas anomalies [149, 150].

2.3.1. History of Radon Discovery

In the investigation of radioactivity in nature, Radon was the fifth radioactive element discovered in 1900 by Friederich Ernst Dorn, as given in Figure 2.29. after Uranium, Thorium, Polonium, and Radium. Firstly, radon was dubbed “emanation” by Dorn as the Radium's progeny but in 1904 Rutherford introduced the name "radium radiation", Ramsay later proposed “niton” it means shining in Latin, but since 1923 renamed as Radon by the international scientific community[151].

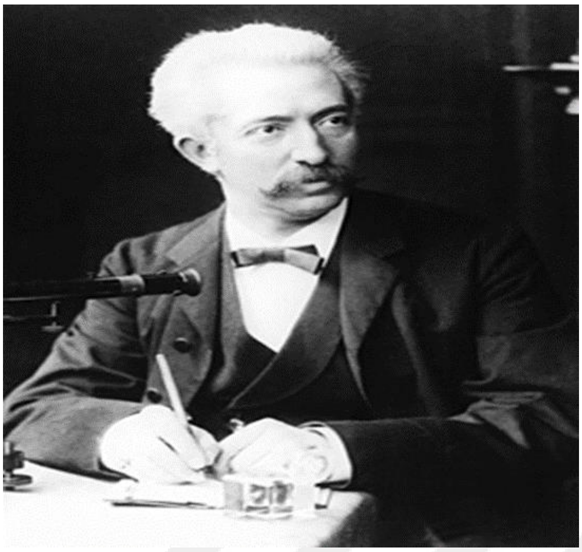

Figure 2. 29. Friederich Ernst Dorn (1848 -1916) [143]

2.3.2. Radon Characterization

Japan's researchers were the first for using radon in the soil for earthquake prediction in 1953 along an active fault zone around two years[152]. It is a highly radioactive gas, which doesn't sense such as color, odor, taste. is the Carcinogenic noble gas for lung cancer that is the second greatest generally identified cancer, Radon generally product in the natural radioactive decay series of ^{238}U, in the soil and crocks, which are gradually turned to the ^{206}Pb, similar sentences as shown in Figure 2.30. during this process will obtain many short-lived radioactive elements all have solid except ^{226}Rn is gas which is the direct decay product of ^{226}Ra. Its common steady isotope, ^{222}Rn has a half-life of barely 3.82 days making it one of the unique radioactive atoms because it decays away extremely fast [153].

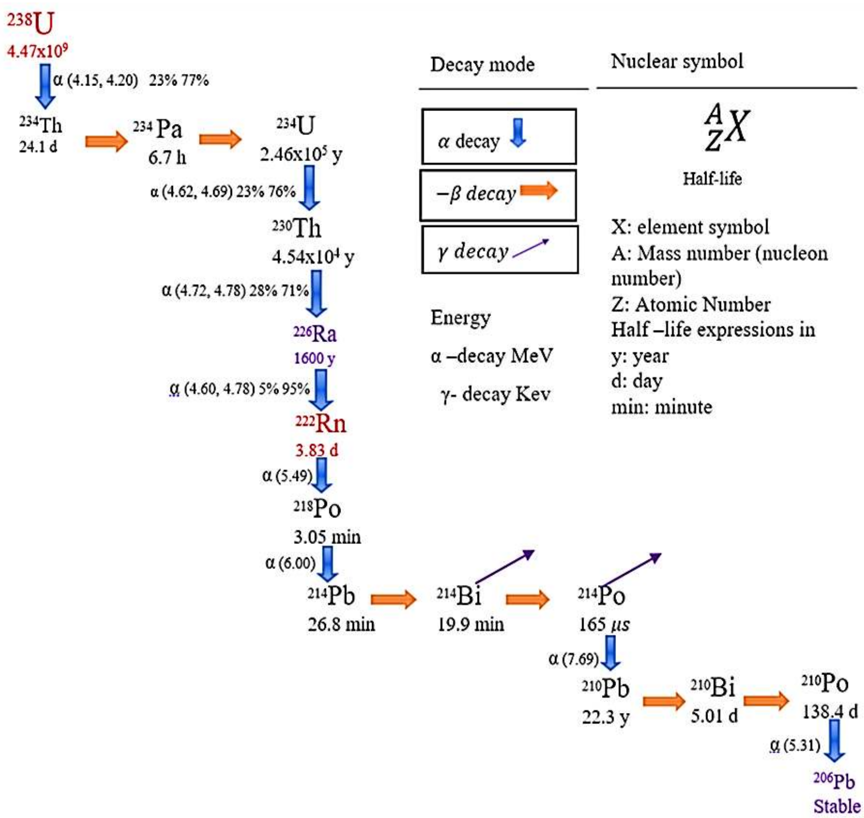

Figure 2. 30. ^{222}Rn product from the ^{228}U decay chain [154]

Despite this, since ^{230}Th and ^{238}U are two of the many common radioactive components on Earth, and both produce three isotopes with distinctly prolonged half-lives, around many billions of years, that is why ^{222}Rn by short half-life, be continuously produced for a long time in the earth's crust, radon decay results in the formation of many other short-lived nuclei known as radon daughters with emitting ionizing radiation in the form of alpha-particles, this leads to the formation of stable lead isotopes at the end, radon Molecular Formula is (^{222}Rn) is radionuclide daughter's which is the inert gas because of low reactivity made it being very movable that persistently regenerated by ^{226}Ra ($t_{1/2}$=1.6 y) decay[155,156]. Radon is one of the heaviest noble gas with highly soluble in water, it has 39 isotopes from ^{139}Rn to ^{231}Rn [157]. Three isotopes of radon that Naturally-occurring are (^{219}Rn or Action, ^{220}Rn or Thoron, ^{222}Rn or Radon) About 22 other isotopes are artificially produced in cyclotrons and linear accelerators[158]. All radon isotopes are radioactive gas formed by emitting alpha particles from the decay chain of ^{238}U which is expected that the average condensation of uranium in the soil is (35 Bq.Kg^{-1}) or 3 ppm [156]. Actually, all thirty-nine radon isotopes are unstable and most of these isotopes are manmade and only a little be present in nature and most stable among them is ^{222}Rn (Radon) due to its unique half-life (3.823 days), radon has a recoil energy 86.0 Kev that can make it easy release from solid grain into pore space, a process called emanation, radon atoms emanated from the soil, rocks, and construction materials then will transfer through the space of these supplies to the pore space and by diffusion and advection will finally exhale from the substantial surface to the atmosphere [159]. Radon radiation in heat lower -71. 15° C its color starting transform from yellow to orange with reducing the temperature, Rn is a little more solvable in water contrast to other rare gases, and its solvability in the mixture of the organic is much exceeding that in water, the RCs in the crust is merely 10 % that of ^{222}Rn, Furthermore, the half-life of ^{222}Rn is greatly time-consuming than other two isotopes ^{219}Rn and ^{220}Rn, for that reason, the word 'radon' mentions to ^{222}Rn, in many cases, [160]. Radon is a natural tracer to investigate air masses, vertical diffusion, and atmospheric researches, in quake forecast, and as a geological sign for uranium and its progeny. Radon settled about 55% of the yearly radiation dose to the worldwide population from all references and 70% from natural radiation sources [148]. Most soils to hold minor aggregates (1 to 3 ppm) of ^{238}U, Generally, the ^{238}U in the soil comprises almost from the same of ^{238}U content of the rock by which the soil was obtained [161]. Radon gas is the main reason of lung cancer after the smoking in united states, annually almost 2000 people decease as a result of human breathing Radon gas from the air and a little amount it will get from water and another source at their house or indoor environment without a ventilator for this toxic radioactive gas, they will be in a higher risk of cancer especially for smokers, despite the lung cancer risk Radon has medical beneficial effects in the treatment of inflammatory diseases most notably such as rheumatoid arthritis and ankylosing spondylitis, but the underlying molecular mechanisms unfortunate are not fully comprehended [162].

For more information about the physicochemical properties of radon gas given in Table 2.5.

Table 2. 5. Some Physical and chemical properties of Radon [163,164]

Physical Radon properties	**Chemical Radon properties**
Density: 9.73 kg/m^3 = 8 times the air's density Half-life: 3. 8235 day Boiling point: -61.7 (°C) Melting point: -71 (°C) State at (20° C): Gas Colorless, Odorless, invisible, and Tasteless. Rare radioactive gas, At standard temperature and pressure, It will radiance consequently of radiation at temperatures below -71. 15° C and changes from yellow to orange with reducing temperature. Radon is a little more soluble in water-related to further rare gases, and its solubility in organic mixes is exceeding that in water	Chemical sign : $^{222}_{88}Rn$ Atomic number: 86 Element Classification: Non –metal Chemical series: Noble gas atomic radius: 1.2×10^{-10} m Electron Configuration: [Xe] 4f ^{14} 5d^{10} 6S^2 6p^6 In periodic table Group: 18 Period: 6 Block: P Its most stable isotope compared with other isotopes and natural gas generate by α-decay product of (^{226}Ra) $^{226}_{88}Ra \longrightarrow ^{222}_{86}Rn + ^{4}_{2}\alpha$

Radon progeny in nature obtained from uranium that is on Earth could exist until the next century that Uranium was discovered in 1789 by Martin Klaproth [165, 166]. Uranium mass in the earth estimated ≈ 0.9×10^{17} kg [167]. The world total Uranium mining content is about 61,134 $\times10^{3}$ kg. that Kazakhstan is the richest country around the world [168, 169]. The major types of bedrocks that contained uranium content illustrated and given in Figure 2.31.

Radiogenic like uranium and its radioisotopes can be found in high concentrations mainly within phosphatic sediments or sediments marine (organic content). Additionally, the brighter granite is richer than other types of rocks for uranium concentration [170]. It is a new way of identifying them. natural uranium occurs as the ^{238}U radionuclide ≈ 99.3% and its half-life is $4.47\text{x}10^{9}$ y [171]. Uranium concentration in Earth's Crust is in the range of 13.5–123 Bq/kg [172]. The content of uranium in the soil that surrounds the water source greatly affects the production ratio of radon per radium in the water, and a linear change can be seen between their variations. The ^{238}U activity concentrations can be calculated by equation (2.12) [173, 174].

$$AU(Bq/Kg) = \frac{C}{\varepsilon\, P_{\gamma}\, Ms} \tag{2.12}$$

When C is the count/s, Ms: is the mass of ^{238}U by (Kg), ε: is the efficiency of the detectors, P_{γ} is the absolute transition probability of γ-decay. but the rate of change of radon is slightly correlated with the concentration of uranium in the earth [175].

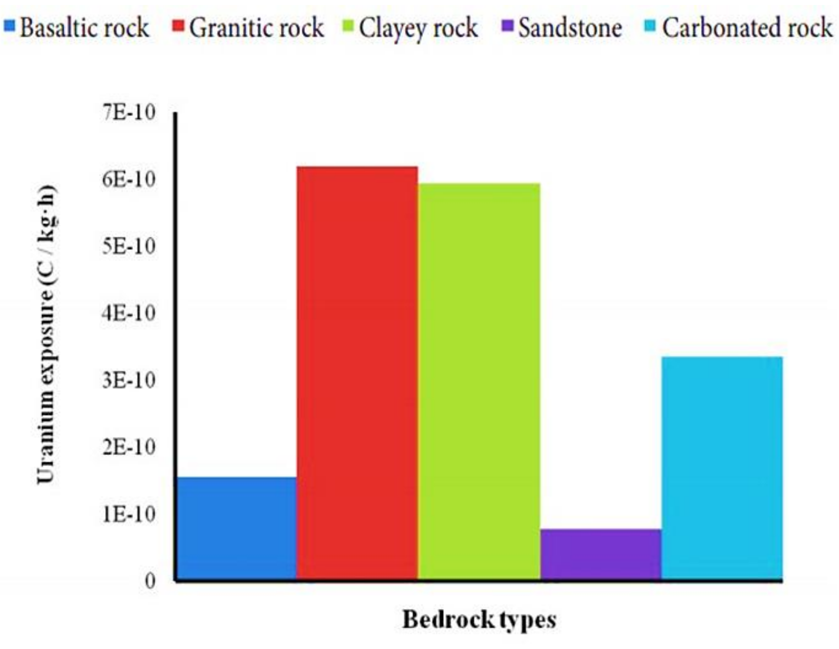

Figure 2. 31. The comparison Based on the richest source of Uranium content in the various bedrocks [176]

2.3.3. Radioactive Equilibrium

1- Transient equilibrium: is a condition of radioactivity that the ratio of the amount of daughter (B) to that of the parent (A) becomes constant in which the absolute amounts of (A) and (B) are changing but their ratio remains the same, and their half-life by a small factor be situated differently. For instance, ^{234}Th

$$\xrightarrow[24.1\,d]{\beta^-} \;\; ^{234}P_a \;\; \xrightarrow[1.18\,min]{\beta^-} \;\; new\ substance$$

$$\frac{N_B}{N_A} \approx \frac{\lambda_A}{\lambda_B - \lambda_A} \tag{2.13}$$

2- Secular equilibrium: in this case that the parent and daughter have a very big difference in their half-life by a factor 10^4, it means $\lambda A \ll \lambda B$, therefore, $\lambda B - \lambda A \approx \lambda B$ [137].

$$\frac{N_B}{N_A} \approx \frac{\lambda_A}{\lambda_B} \tag{2.14}$$

or

$$\lambda_A N_A \approx \lambda_B N_B \tag{2.15}$$

For instant:

$$^{238}\mathrm{U} \xrightarrow[4.5\times 10^9\ y]{+2\propto} \;\; ^{234}Th \xrightarrow[24.1]{\beta^-} \; new\ substanc$$

The accumulation of radon from radium is typical for this case and the progress of ^{222}Rn from ^{226}Ra given in Figure 2.32.

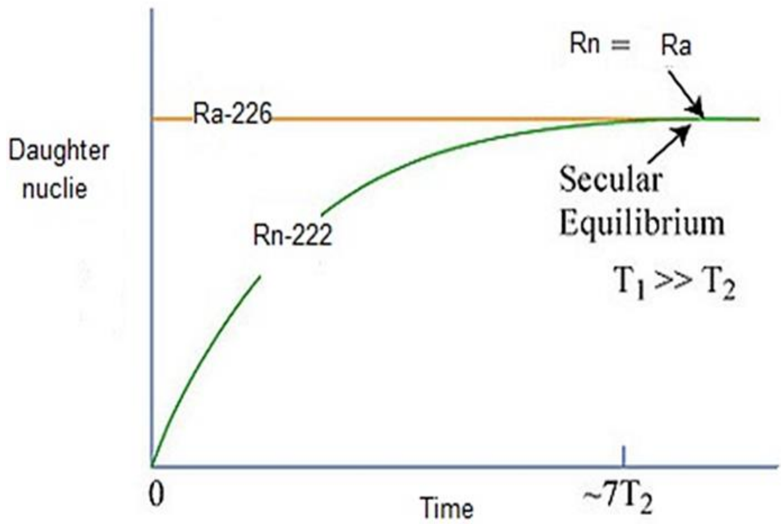

Figure 2. 32. Build-up of Radon from Radium [177]

2.3.4. Alpha Decay

Since 1898, Rutherford discovers (α-particle) [148]. (α-particle) is the nuclei of a helium atom that has two neutrons and two positively charged protons, they have a short-range for high-energy transmission, which can damage the DNA structure inside human cells by inhaling air, as a result, it causes lung cancer. and Radon progeny or Radon daughters (solid elements) such as ^{218}Po, ^{214}Po, ^{214}Pb, emitting Alpha radiation [178].

An α (alpha) transition is described in Figure 2.33.by the source of ^{226}Ra decays immediately to the last energy level (ground state) of the descendants ^{222}Rn in 94% of all shifting, in 6% of the shifting, ^{226}Ra decays to an intermediate higher energy state of ^{222}Rn, which then decays to the ground state by isomeric conveying for any transfer paths, the transition energy amid source and ground state of the descendants is constant. In the instance of ^{226}Ra, the conveyed energy is 4.78 MeV, given in Figure 2.33. radon gas generates by α-decay product of (^{222}Ra) [$^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}\alpha$] alpha particles because of positive charge can be reflected in electric and magnetic fields. The velocities range from about 1.4x10^9 to 2.2x10^9 cm/sec, or less than $\frac{1}{10}$ of the velocity of light [179].

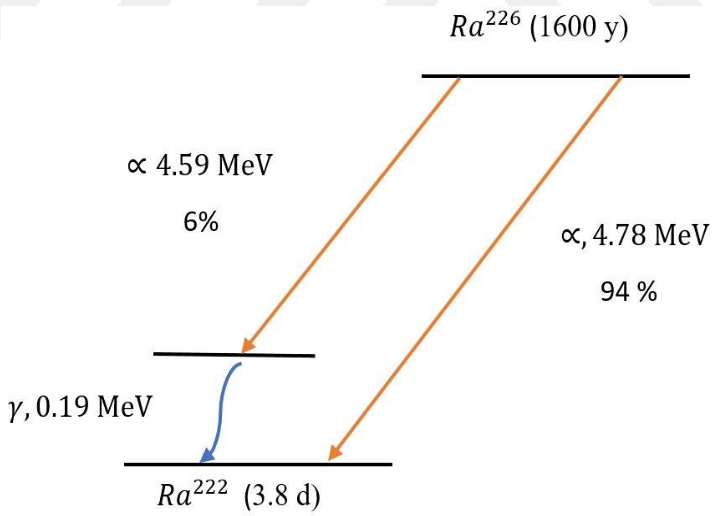

Figure 2. 33. Radioactive decay scheme, α - decay of ^{226}Ra [177]

2.4. Radon Migration Through Soil Pores

To comprehend the geology of radon movement and its forming from the soil, we have to know about the base radionuclide sources for radon atom, for instance, radium content and uranium amount inside of earth's layers, rocks possess three foremost forms to include (metamorphic, sedimentary, igneous) because all rocks contain some uranium, although most contain just a small amount between 1 and 3 parts per million (ppm) of ^{238}U or 10^6 pounds (5×10^5 kg) of rocks mostly will have 0.45 to 1.35 kg of ^{238}U spread through it. Averagely 80% of radon come into the air from the upper layers of earth, underneath the lithosphere has complex physical mechanisms such as geophysics phenomena including Earth seismic and volcanic activities that might make pressure slope, wherein get the radon occasion to penetrate among the rocks toward up the troposphere with regards to both main influencers (hydrogeological and geochemical) in the soil for emitting radon gas before and after quakes[180].

Soil formed by the natural powers process which are Rapid changes to the land such as earthquakes, volcanic activities, floods, and slow change to the land by weathering and erosions to the factors of temperature on seasons in the year, the storms which cause for the erosions, destroying and changing rocks in the layer of Earth's crust. Consequently, most soils to hold minor aggregates (1 to 3 ppm) of ^{238}U. Generally, the ^{238}U the soil comprises almost from the same of ^{238}U content of the rock by which the soil was obtained [161].

Radon's properties averred to its use as a geophysical tracer for locating buried faults and geological structures, in exploring of uranium, and for predicting earthquakes. Radon has also been used as a tracer in the study of atmospheric transport processes. Radon atoms located within solid grains are unlikely to become available for release to the atmosphere, owing to their very low diffusion coefficients in solids, therefore if they are located in the interstitial space between grains, they may diffuse to the surface, the source term increases with the emanation coefficient, the radium activity concentration and the bulk density, therefore, Processes leading to radon release to the atmosphere depending on the factors controlling radon releasing from soil to the atmosphere will happen by the following series of processes :

(a) Emanation: radon atoms formed from the decay of radium escape from the grains (mainly because of recoil) into the interstitial space between the grains. It is generally accepted that radon escapes from grain as a result of its recoil when its parent, radium, decays, as the recoil range in solids is small, typically less than 0.05 μm, most of the recoiling atoms remain within the mineral grain lattices.

(b) Transport: diffusion and advective flow cause the movement of the emanated radon atoms through the residue or soil profile to the ground surface. the leading transport mechanism is diffusion; hence the transport of radon is generally mentioned as diffusion [181].

(c) Exhalation: radon atoms that have been transported to the ground surface and then exhaled to the atmosphere [182]. Radon atoms transferred to the Earth's surface then enters to the ambient air(outdoor) or Radon transportation flux from the initial origin to the indoor environment is called radon exhalation which made from many references such as soil, sand, rock, structural materials, uranium waste, and uranium ore radon exhalation can be measured by exhalation rate that specified as the number of emitted atoms from substance per unit surface area per unit time and named “Exhalation flux density “showed in (Bq /m^2.s) [183].

Radon naturally generates from the uppermost layer of the earth due to the radioactive decay of uranium and thorium can be transferred from soil into the atmosphere before proceeding to be stable by the reason of spontaneous radioactive decay due to the definite half-life time of three common radon's isotopic, for example, the special half-lives are 3.8 days for ^{222}Rn, and 56 s for ^{220}Rn, 4 s for ^{219}Rn, Radon transfer via soil pores chiefly by molecular diffusion, the mediocrity rate of RCs from undisturbed soil into the earth's Atmosphere are 0.015-0.048 Bq m^{-2} s^{-1} Radon's typicality is used as a geophysical tracer for discovering the exact place of uranium in the earth's layers, and for predicting the earthquake, radon is not made by humankind in the ground because of this radioactive gas generated out of radium-226, which is found in uranium ores, phosphate rock, shale, igneous and metamorphic rocks such as granite, gneiss, and schist to a lesser degree, in common rocks such as limestone, radon is produced in environments such as underground rocks, coal, and soils, after which it migrates to the surface and goes into the atmosphere, the entire process is defined as radon release, the process of radon emission can be divided into two stages formation of free radon and departure of radon gas, the first step, radium atoms decay in the surface layers of the earth's crust and produce alpha particles with radon atoms, the recoil of the atom and its diffusion effect causes the radon atoms formed from the rock crystal lattice to break into micro cracks and become free of radon. In the second stage, free radon migrates to the surface through cracks and pores and goes into the atmosphere, processes that start from the inside of the earth, and eventually lead to the release of radon gas from the earth's surface into the atmosphere [184]. As can be seen in Figure 2.34.

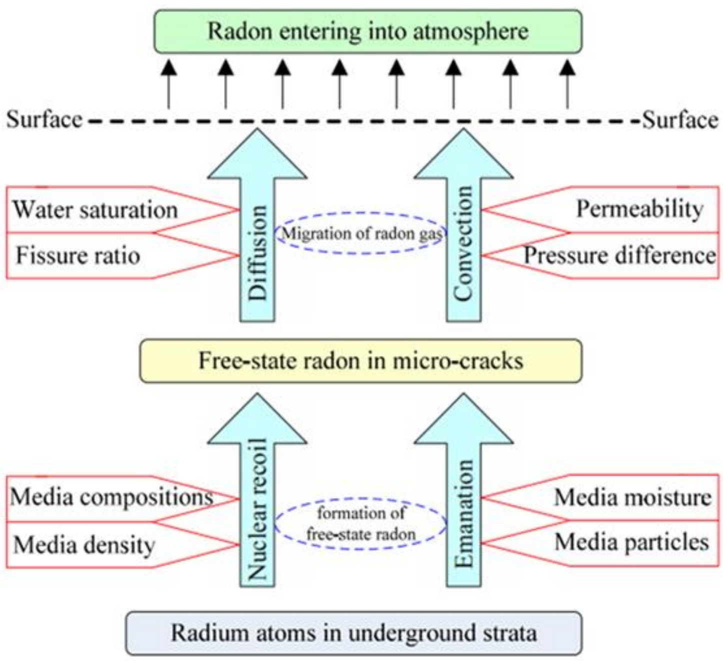

Figure 2. 34. Processes that lead to the release of radon into the Earth's atmosphere [185]

2.4.1. Diffusive Transport

In 1829 at Kassel(Germany) Adolf Eugen Fick was born, he studied physics and mathematics, and in 1851 he succeeded a doctorate in medicine from the University of Marburg He only had 25 years when he turned on an investigation of diffusion in liquids, mentioning discerned a relationship between heat diffusion and liquid diffusion he approved Fourier's heat conduction equations as his fundamental model for diffusion. in 1855, he declared his paper titled "Fourier's model applied to molecular diffusion", he showed what it is presently recognized as Fick's laws, knowledge of diffusion in gases, solutions, and liquids was considered of scientists in the last half of the 19^{th} century about the composition of fluids that consequence the kinetic hypothesis of gases, Fick's and Einstein's equations, the door was open to new investigations in order to define diffusion coefficients in solids and know the atomic mechanisms in the framework of theoretical advancements, particularly in relationship with models of random walks and leaving from completely random motions which named "correlation factors", their research held exceptionally satisfied with numerical simulations by the Monte-Carlo techniques, a significant stage in diffusion measurements was completed by the Hungarian scientist György von Hevesy (1885- 1966), he operated in many prominent positions with well-known experts such as A. Rutherford, H. Moseley or N. Bohr that he was undoubtedly the first person that figure out the importance of radioactive tracers as an instrument in geophysics and geochemistry, he bestowed the Nobel Prize in Chemistry in 1943, and in 1946 his book published titled "Radioactive Indicators" published [186].

Radiotracers were widely applied after World War in several different techniques amplified by many scientists in different countries because this procedure provided highly precise measurements of diffusion coefficients in most solids. Then, other analytical machines were ready to support new diffusivity calculating, but Fick's name remains famous in the history of cardiology and as the first author in medical physics. Fick's first law describes how the condensation and the flux are connected. By presenting the hypothesis of a Stationary state [187].It is sometimes difficult to understand all the details but a very careful analysis of Fick's experiments has been carried out by T.W. Patzak [188].

Fick's Law and the Diffusion Coefficient, owing to random molecular motion, there is a net migration of gas molecules from regions of high concentration to regions of low concentration, on a long-term average basis, available evidence suggests that radon transport from the soil into the atmosphere occurs predominantly by molecular diffusion [189]. This section quantifies the rate of radon migration through soil due to molecular diffusion, radon transfers from side to side soil pores essentially by molecular diffusion [154].

Investigators in Marie Curie's group put forward the idea that some solid materials diffusion radioactive inert gas and should investigate by attention to it as a modern issue of physical and chemical analysis [131].

The flux density that results from random molecular motion is described by Fick's law, for dilute concentrations of radon in the open air, Fick's law may be written as $J_d = -D_\circ \nabla I_a$ where J_d is the radon activity flux density due to diffusion (Bq .m $^{-2}$ s^{-1}), $D_\circ$ the molecular diffusivity (m^2 s^{-1}) I_a is the activity concentration of radon (Bq m^{-3}), and Δ is the gradient operator (m^{-1}), radon in the environment is always present at dilute concentrations, a typical indoor concentration of (50 Bq m^{-3}) corresponds to a mole fraction of 9.5 x 10 $^{-19}$ for ^{222}Rn and an even smaller mole fraction for ^{222}Rn, Fick's law is based on experimental observations and its consistent with a kinetic theory for an ideal gas, the diffusivity of ^{222}Rn in the air is 1.2 x 10 $^{-5}$ m^2 s^{-1} Considering the diffusion of radon through soil pores, we need to adjust our description to account for two effects of the solid matrix, the area through which radon may diffuse is reduced and the average path length that radon must traverse to reach one point from another is increased, these factors are embodied in the replacement of the binary diffusion coefficient $D_\circ$ with an effective diffusion coefficient D_e so that J_s^d= -$D_e \nabla I_a$ in this equation, I_a represents the radon concentration per volume of soil gas, J_s^d represents the diffusive flux density of radon activity per unit of air-filled pore area of the soil, and the gradient operates per unit length through the bulk soil, In reading the literature, one must be cautious because there is no standard way of writing Fick's law for porous media, differences arise when concentrations or fluxes are written in terms of total volume or area instead of air-filled pore volume or area, transport by molecular diffusion of radon in soils is limited because of its short half-life, migration by diffusion ranges from about 5 m in gravel to about 2 cm in mud or clay and distances greater than 1 m are probably unusual [190]. Present-day Earthquake seismology shows that migration of soil gases mostly depends on the availability of favorable subsurface structures such as uranium content in soil and temporal variations are related to soil moisture variations as the molecular diffusion in the unsaturated soil zone depends on available air-filled pore space, the corresponding seasonal variations with low fluxes in winter and high fluxes in summer range, due to the difference between the two region's radon concentration, Radon can migrate between those regions by diffusion Fick's law and diffusion rates [191]. As can be seen in Table 2.6.

Table 2. 6. Average diffusion distances of radon isotopes in diverse media [192]

	^{222}Rn (cm)	**^{220}Rn (cm)**	
Medium	**Mean distance**		**Diffusion constant (cm^2.s^{-1})**
Air	220	2.85	10^{-1}
Porous soil	155	2.0	$5x10^{-2}$
Water	2.2	0.0285	10^{-5}

Atmospheric meteorological parameters can influentially effect on the soil-air emanation rate, including moisture add-up, heat, wind velocity, and aerial pressure, agent values of the activity of RCs = 40 Bq/m^3, flux rate of radon moves out the Earth's surficial is (J_d= 0.026 Bq/m^2 s),According to Fick's law, we will discern that under standard required conditions, radon will diffuse simply a few meters from its locality of formation [27]. due to the Diffusion constant for dry soil D = 5 to 6.8 $\times 10^{-6}$ m^2. s^{-1} [17, 193]. The skyward releasing radon through faults is normally at a higher concentration than radon diffusing and scattering in the soil surface. Because the outcome of RCs is high in active fault zones high RCs in the range of 20 to 80 KBq m^{-3} are reported in active fault zones universal [194].

The advection: is a fundamental factor in the process of radon transportation in the subsoil because it will help soil gas to flow and penetrates through the underground to the environment, the advective flow is influenced by weather conditions such as wind and differences in indoor and outdoor temperatures, diffusion is considered to be less effective than advection in condition high concentrations for indoor study, Darcy's law describes the advective transport [154].

2.4.2. The Formation of Radon (Emanation)

Only a fraction of the radon generated in soil ever leaves the solid grains and enters the pore volume of the soil. The fraction of radon generated in soil that escapes the grains is known as the "emanation coefficient" or "emanating fraction" or "emanating power" Many investigators have made the experimental measurement of the emanation coefficient of rocks and soils. We have some understanding of the basic physical processes leading to radon emanation from soil, however, measured emanation coefficients are considerably higher than would be predicted by simple physical models. Conservation of linear momentum dictates that upon being created by the alpha decay of radium, ^{222}Rn and ^{220}Rn atoms possess kinetic energies of 86 and 103 keV, moisture content has been demonstrated to have a large effect on the emanation coefficient of radon from uranium ore tailings, an excellent rate of radon emanation happens while the soil is between 15% and 30% moisture [183].

Temperature also is a factor in determining the radon emanation coefficient although, over the range of temperatures common for surface soils this effect is probably of minor importance, some investigation found that the radon exhalation rate in a soil sample increased by 55% when the temperature was increased from 5° to 50°C. They suggested that the increase in temperature may be due to a reduction in physical adsorption of radon onto soil grains [195]. Investigate found a much smaller temperature dependence for the emanation coefficient of a granite sample,0.106 at

265°C to 0.081 at -20°C. He found though that when the sample was cooled to -80°C, the emanation coefficient decreased markedly to 0. 028, We may consider that the radon atoms in the soil are distributed among four states: (i) bound within the solid grains, (ii) sorbed onto the surface of soil grains (sorbed phase), (iii) dissolved in water contained in the soil pores (aqueous phase), and (iv) dispersed within the gas contained in the soil pores (gas phase), as discussed in the previous section, diffusion from the first of these states to the gas phase is negligibly slow, the exchange of radon atoms among the remaining three states may be rapid relative to radon's half-life, if the sorbed and/or dissolved phases represent sizable reservoirs relative to gas-phase radon, then the presence of radon in these condensed phases must be considered in the design and interpretation of experiments and the analysis of radon transport through the soil. At equilibrium, the partitioning of radon between the gas and aqueous phases is described by Henry's law, which may be written as $I_w = \kappa I_\alpha$ where I_a represents the radon concentration in the gas phase (Bq per m^3 of pore air), I_w, represents the radon concentration in water (Bq per m^3 of water), and κ is a dimensionless partition coefficient, which is a function of temperature, measured values of the partition coefficient for radon between distilled water and air are 0.506 at 0°C, 0.340 at 10°C, 0.245 at 20°C, and 0.193 at 31.6°C, in applying Henry's law to the problem of radon transport through soil pores it will be assumed that the pore water possesses thermodynamic properties similar to those of bulk distilled water, it will also be assumed that equilibrium is rapidly achieved and maintained, (A characteristic time for diffusive transport across length L is given by $\tau \sim L^2/D$, where D is the molecular diffusivity. Even for a relatively large soil pore dimension of L ~100 μm, the corresponding time for radon diffusion is brief; 10 s if water-filled and 0.001 s if air-filled) Both assumptions appear reasonable but have not been experimentally tested in this context. Until very recently, most analyses of radon migration in soil were based on the assumption that radon did not interact with the surfaces of the soil grains, Although several prior investigators had suggested that sorption phenomena might occur, the central findings of their work suggest that sorption may be very important in laboratory studies of radon emanation and transport in dry soils but that sorption effects are likely to be small under the soil moisture conditions normally found in the environment, a parameter for conveying the importance of sorption was defined by Schery and Whittlestone as the ratio of radon sorbed to radon residing in the pore air, for three samples of soil (silty clay loam, sandy clay loam, and lean clay) this ratio was found to be in the range 3-17 for dry soils at 0°C but less than 0.2 for soils containing moisture 10% of their dry weight and 20°C, given that radon in the soil, pores are present in dilute concentration and at temperatures far above the point of condensation, the use of a linear sorption isotherm is an appropriate description of the equilibrium partitioning of radon between the gas and sorbed phases: $I_s = \kappa I_a$, I_s represents the sorbed concentration of radon (Bq per kg of dry soil) and κ is the partition coefficient for sorption (m^3/kg), the parameter defined by Schery and Whittlestone is given by $\phi = \rho K/\varepsilon$, where ρ is the dry bulk the density of the soil (kg/m^3) and ε is the porosity (pore volume per bulk volume) [196].

Recoil Emanation (Rm):

This phenomenon occurs between ^{226}Ra (radium) and its progeny (radon) by the alpha decay process with energy recoil (E_R) 0.86 MeV for ^{222}Rn (Radon) and 0.108 MeV for ^{220}Ra (Thoron) respectively. The emanation of radon recoil does not stand by to its half-life law, Radon recoil depends on the ^{226}Ra position and the range of the event of recoil to the surficial, that is why Radon and thoron have the same emanating power in some case of measurements. Outward from soil to the surficial. In another word, radon has a finite range (Rm) in the materials. Regardless of their half-life. And according to Zimens formula, it can be calculated by equation (2.15)

$$R_m = C\,\frac{1}{\rho}\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{a_i}\left(\frac{A}{B}\right) i \text{ (nm)} \tag{2.15}$$

C (Lab result constant) = 5700 Rn

ρ = (specific gravity) (kg/m^3), $\mathrm{a_i}$= atom fraction of element i; A= Atomic mass of element i;

B= stopping power of element i relative to air. It depends on the atomic number(z), the range of Radon in clay is 35 nm and for air is 65 µm, according to the zaman's formula. It means that ^{222}Rn recoil emanation is related only to ^{226}Ra progeny formed at a depth less than (Rm), radon particles shaped in the alpha-decay of ^{226}Ra which has a recoil (K.E) of 86 KeV based on the energy conservation rule the recoil displacement from the radionuclide parent atom will be signified by the Nuclear recoil effect. Determining SRG concentrations from highest to lowest Capacity can be arranging 1-granitic, 2-volcanic, 3-sedimentary, 4-metamorphic, respectively [17]. The conformation and concentration of the radium decay region will determine the distance of the radon atoms penetrating in its area that qualified by the recoil process. Indeed, the quantity of emanated radon atoms ought to reduce while grain size growths as a result of reducing of the total surface area of the grains If the soil is dry, the detectable distance for radon diffusing and dispersing in the soil is within several meters a significant part of radon atoms emanated from radium decay, the major condition for radon releasing atoms from the soil will be increased by dryness of the soil, radon formation is a process that becomes from decay chain of ^{238}U that is present in all rocks and soils, due to the half-life of ^{238}U is 4.47×10^9 years by this reason it's 4.47×10^9 years timeworn rocks have merely half of the ^{238}U by which it has been beginning. Consequently, Rn and Ra for the reason that is produced by the radioactive decomposition of ^{238}U, any atom of ^{226}Ra -decays by emitting from its nucleus an (α- particle) compounded of both Neutrons and double Protons. Utilizing the (α- particle) is emitted, the recently shaped ^{222}Rn atom recoils, alpha-particle recoil is the main driving force to escape radon from in mineral grains. Regardless of its half-life [197]. As can be seen in Figure 2.35.

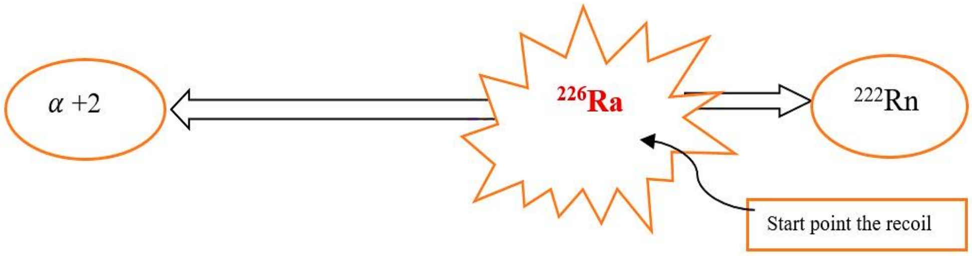

Figure 2. 35. Recoil radon and alpha particle with conservation momentum from radium decay.

In consequence of the sufficient energy produced to transmission radon atom from the soil's structure so that makes the displacement of radon is about (40 nm), these processes identified as alpha recoil. It is identified that the range of ^{222}Rn is between 20 to 710 nm in solids, 100 nm in water, and 63 μm for air [198].

The emanation coefficient, which refers to the fraction of radon produced in a substantial that pass in the pore fluids, differs over a wide range with a representative value being 0.2 or the fraction of radon atoms created from ^{226}Ra decay which escaped from grounds soil vents will know as the radon emanation coefficient or emanating power of the material. Grain size and shape are the significant reasons which can control the radon emanation coefficient for the reason that they control in part how much uranium and radium are near enough to the surface of the grain to let the newly-formed radon to escape into vents of soils space [199].

Radon Gas in Soil pores can be divided into three forms: in the pore air, sorbed to the soil grains, solvable in the pore water, before radon decaying completely, it will enter the pores of the material, and few amounts of emanating radon can be reached to the surface, the possibility for this to pass linked essentially to the transport features of the medium, this dispersive transport takes radon to run in a reverse way to the radon concentration gradient according to Fick's law. Soils developed from analogous parent rocks in different areas have remarkably dissimilar emanation coefficients caused by the factors of changing weather on these soil features [30].

Rn atom move in the pore space between mineral grains depended on two situations, first is the place of the ^{226}Ra in the mineral grain or from the surface of the grain, second the direction of the recoil of the ^{222}Rn that is in the direction of the uppermost layer of grain or the inner side of it, as can be seen from Figure 2.36. if ^{226}Ra has been middle within a large grain irrespective of the orientation of alpha particle recoil, it would not let to the ^{222}Rn from the grain and the radon atom will stay fixing in the mineral, notwithstanding, the recoil of some radon atoms which close to the surface of grain is steered to the outside of the surface of the grains, while these occur, the last shape of ^{222}Rn will release from the rock crystal and it will enter the aperture gap amidst the cracks in the rocks, if the water is existence into the pore space, though, the mobility ^{222}Rn extremely fast will be decreased and is extra probable to remain in the pore space. Just ten to fifty percent of the Radon gas that created essentially outflows the mineral grains and going into the pores [200].

The amount of radon transferred to the surface is expressed in the radon production rate per unit volume. And can be calculated by ($P = \lambda E R \rho_b$), when P: is Radon production by Bq/m^3.s λ: is Constant decomposition of radon according to s^{-1}, E: is Emanation coefficient(without unit), R: Radiation concentration of radium at the site of measurement Bq.Kg^{-1} ,and ρ_b**:** the density of materials or mass measured by Kg/m^3, if the grain-size was bigger than 1 µm it does not affect radon emanation significantly, the moisture of soil commonly increases the emanation fraction by a factor of 5 or less, the indicative measures of the emanation fraction approximately for each mineral obtained 0.03, rocks are 0.13, and soils are 0.20 [159]. As can be seen from Table 2.7.

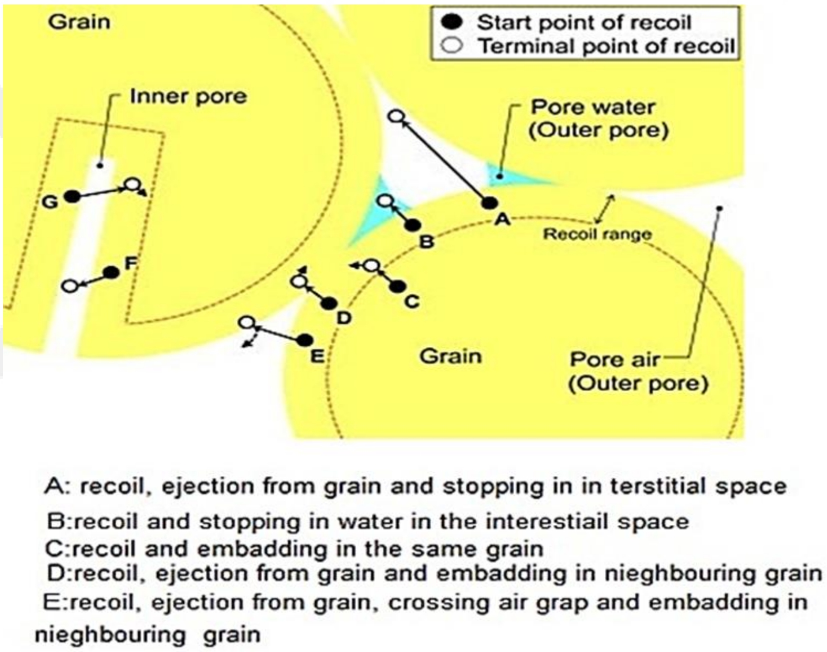

Figure 2. 36. Indicate the radon emanation process in between grains, recoil path, etc. Will specify whether the freshly created radon can release to pore spaces, emanation: points (A, B, E, and F) or will remain in the grain (not emanation: points C, D, A) [159]

Table 2. 7. Standard concentrations of ^{226}Ra and ^{222}Rn in soils, measured at a depth of 1 m [192]

Soil type	^{226}Ra (Bq.Kg^{-1})	^{222}Rn (Bq.m^{-3})
Till or residual soils with normal radium content	15-65	5,000-30,000
Till or residual soils with fragments of granite	130-125	10,000-60,000
Till with fragments of uranium-rich granite	125-360	10,000-200,000
Gravel	30-75	10,000-150,000

2.5. Radon Potential

Geochemical and geophysical investigations presumed that the most influential technique of knowing zones of high radon potential is the soil gas radon measurement [30]. Generally, the density and the flow of radon in the soil are dependent on various factors, the most influential including (i) the soil's parent radionuclide as uranium content. (ii) distribution, porosity, permeability, and moisture in soil composition can describe radon migration and its concentration [201]. These features are, successively, defined by the nature of the bedrock, glacial deposits, or carried sediments from which the soil was originated, also the climate and soil's lifetime [30, 202]. To distinct mechanisms play an essential role in the discharge of radon or ^{226}Ra progeny from soil (i) diffusion, ^{222}Rn passes with considering the fluid fills the pores of the medium and (ii) transport (convection) where the fluid itself flows through the porous medium and transfers the Rn along with it, radon is a terrestrial radioactive progeny that is continuously generated all over the earth's crustal materials, by understanding the geology of the research district, experts can assess the radon potential for the rocks and soils of faulting sites. Certain circumstances can enhance the opportunity that an area will have a higher percentage of radon gas soil modifications detection directly from the soil, radon shows to be one of the most assuring precursors and is the tracer for which more data are prepared: according to statistics obtained in China, 70% of quakes are predicted by radon anomalies sortable in soil, air or in groundwater. However, 40% of the radon anomalies identified are not served by earthquakes [203].

The geological map will assist researchers in identifying the research district about its mineral formation and natures of rocks [204]. And (radioactivity map) that will indicate the number of Uranium isotopes and their progeny in the surficial rocks and soil that are composed in the area that part has more uranium content and its progenies [205]. the change in uranium concentrations depended on the deformation of saprolite and soil composition, the granites that have the most uranium emit the most radon [202]. Radium and its progenies can be found in the groundwater system Admittedly ^{222}Rn has a very brief half-life of only 3.82 days. It is generated by the decay series of ^{238}U, ^{234}U, and ^{230}Th all of which have long half-life and sustain in granite, igneous rocks, sedimentary rocks, metamorphic rocks, etc. Rn has slow diffusivity in soils as mentioned before distance displacement of Rn in the soil is relatively short, due to its small half-life and slow diffusivity in soils, for instance, the diffusion coefficient of radon in dry soil as 5×10^{-6} m^2/s, the average diffusion length in 3.82 days is found to be 1.6 m [17].

Radon measurements in groundwater and soil have been shown that spatial and temporal changes to yield information about geodynamic phenomena. The difficulty of the definition of exception and its parameters (amplitude, duration, center distance, and precursor time) [206, 207]. precursor time and anomalies will increase with both magnitude and distance from the epicenter of the earthquake [24]. We can determine the distance at which we can perceive an anomaly attributable to an assumed earthquake by this relationship ($M \geq 2.4\, log_{10}\, D - 0.43$), while M: is the least magnitude necessary to get a radon anomaly at distance D (km), but one of the first experimental links for the study of the time precursor we have to use this relationship ($\log t = 0.76$ M - 1.83), while (t) represented to the time precursor, and (M) is the magnitude of the forthcoming earthquake, in the area of reversal faults, higher fluid flows are expected than with normal faults during interseismic control. Therefore, soil gas exploration is important in identifying fractures of the compressional regime [14].

An area that has bedrock near to the surficial that is covered with thin soils or on that area that has fractures in the underlying rocks which hold limestone fissures, RCs tend to be high at faults [208]. The extremely permeable soils are the soil that has the lowest water content and wet clay can trap the radon gas delivering with the lowest permeability and conversely dry clay carried high ability to emanate radon gas due to its desiccation cracking, otherwise fault with higher slip rate causes more radon degassing [209].

Conceivably meteorological effects aren't dominant on RCs relative to the stress which made by an earthquake on very active faults seismic area. Herein radon transfer processes carry out along the faults zone before earthquake increasingly, and after the earthquake, it will be decreasingly, and during the earthquake, RCs anomalies will get the top of its rate [210].

To comprehend the rise of radon gas before and during a main-shock of earthquake close a fault is required to review the Dilatancy-Diffusion theory of earthquake precursors, the theory describes the front steps starting to an earthquake based on the study of variations in the physical properties of rocks with dilatant strain in lab experiments. that rocks "dilate" under stress, enhance their volume through deformation; by an expansion in pore volume and its distribution, variety in cracks, the mechanic acts of grains[211].

The hydrological factors that have a direct effect on radon content of air over and close to the soil surface such as atmospheric pressure, temperature, precipitation, and winds [212].

Three main classify are Radon gas emission, fluid convection, and stress, gases can be released due to oil deposits and pressurized by hot ground such volcanos, likewise, stress can be generated by the gradual increase of the strains that precede earthquakes and volcanic eruptions can help the uranium transportation in deep points underground to closer point of ground surface and it will help to increase the radon concentration that can reveal impending activity [192].

2.6. Radon Measurement Methods

As was mentioned before, because of the long half-life of ^{222}Ra than other isotopes and its diffusion length extent. ^{222}Rn decaying with alpha particle emission in such case the measurements can be executed directly on ^{222}Rn itself called Radon alone measurements or incidentally on radon or its daughters. Radon and its progenies decay via α- particles, while these radon products of ^{214}Pb,

^{214}Bi, ^{210}Pb, and ^{210}Bi are also β-emitters, as well as γ-ray, accompany their β-emission, therefore, radon detection and measurement can be performed through the detection and measurements of these radiations by understanding essential detection sensor information of interaction of these radiations with the matter, many techniques are available for measurements of radon, these are classified into two main categories passive and active detectors techniques [177].

Passive Detector Techniques:

Long-term measurement: is a measurement of RCs covering a period of three months up to one year [213]. Radon enters the detection system by natural diffusion [24]. The passive detectors are the most widely used technique, particularly the nuclear track detectors CR-39 equipped with the sealed can technique, which incorporates the effect of seasonal, weather, and environmental conditions on radon concentration in the dwelling. It is very important to carry out measurements over a long period. Passive devices are the most widely used and practical way to determine radon concentration, where the detection sensor generally located the inner part of a container. The container is the way to keep the detector by preparing conservation places around the detector for sensitive big volume enough to have many α-particles manufactured and identified in a little time as possible. There are other types of passive detectors such as TLD, Electrets, Charcoal canister technique, (SSNTD) [214].

Active Technique:

Short-term measurement: is a measurement of RCs covering less than three months [213].

The active technique generally working by Radon pumping into the device [215].

These devices are used normally for short-term measurements, the active technique is based on the method in which grab sample of air is collected at the instant time followed by measurements of radon concentration through α-particles activities. The active measurement techniques are not so beneficial to accurately measure the radon levels because of temporal variation in the radon level due to the temperature and pressure gradients. Examples of these techniques are the Lucas cell and ionization chamber [216]. Long-term and short-term radon anomalies have been performed in multiple places around the world, both have performed an impress in the forecast of many major earthquakes [217]. Especially in China's earthquake predictions history, 50% of them used geochemical fluid precursors [215].

3. METHODOLOGY

The path to be followed in the application part of this work can be summarized as follows:

i. Earth radon gas exchange data from the station located in Erzincan Ekşisu has been given by the General Directorate of Disaster Affairs of the Prime Ministry under the scientific agreement we have made so that we can use scientific studies. Historical earthquake data within 100 km of Ekşisu will be supplied from Bogazici University Kandilli observatory.

ii. On the other hand, all meteorological change parameters from the General Directorate of Meteorology will be supplied. Thus, time series analysis can be performed and the physical mechanisms will be interpreted. These variables are; Daily 07 sunshine 10 cm soil temperature (°C), daily 07 sunshine 20 cm soil temperature (°C), daily 07 local 50 cm soil temperature (°C), Daily steam pressure (hPa), Daily wet bulb temperature, Daily dry bulb temperature.

iii. To reveal the relation of Earthquake-Rn gas, three-dimensional diagrams will be drawn and interpreted. With these diagrams, the Earthquake-Rn estimate deductions will be made.

iv. Classification of Earthquake-Rn data; the values of the earthquakes corresponding to the radon data are found and the earthquake prediction is performed conditionally on the radon value.

3.1. Time Series Analysis:

Time series analysis is related to statistical data, therein time is a dimension to demonstrate many variables that changed their disciplines, such as yearly, monthly, daily scales. By time series analysis can be examined. the main trend of time-series by three methods can be measured, (i) semi average, (ii) moving average, (iii) least squares, there are many studies showings that analysis of ^{222}Rn behavior with Time Series provides important information about possible earthquakes, for example, investigators Showed by Time Series analysis that the RCs in water and soil increased approximately 70-99% in 21 days before the 5.4 magnitude earthquake that occurred in İçme (Elazığ) located on the East Anatolian Fault on June 23, 2011, as can be seen in Figure.3.1 [218]. And the concentration of ^{222}Rn in 1965 increased rapidly and the initial concentration value increased approximately 3 times on April 20, 1966, and Monitoring the ^{222}Rn temporal change before the Haicheng earthquake, which occurred in size 7.3 in China, predicted the earthquake that would occur a few hours ago, and It was determined that the temporal change in the concentration of ^{222}Rn contributed to the earthquake prediction in the major earthquakes in China during 1975-1977, again, the temporal variation of the concentration of ^{222}Rn was examined at Kutzan station in China during 1972-1976, and it was observed that the level of ^{222}Rn increased by 36- 120% in 6-13 days before the earthquakes in 8 of the 9 earthquakes [219].

Time Series Analysis provides great convenience for the detection of different or contradictory situations in the analyzed data. The determination of these data is very important for the correct evaluation and interpretation of the behavior of the examined variable, for this purpose, it was tried to interpret the changes by drawing Time Series graphs showing the change of ^{222}Rn concentration with earthquakes, although noticed there are no big differences in meteorological variables in the same seasons at different dates, it can be said about differences which occurred in the RCs was only caused by seismic activities.

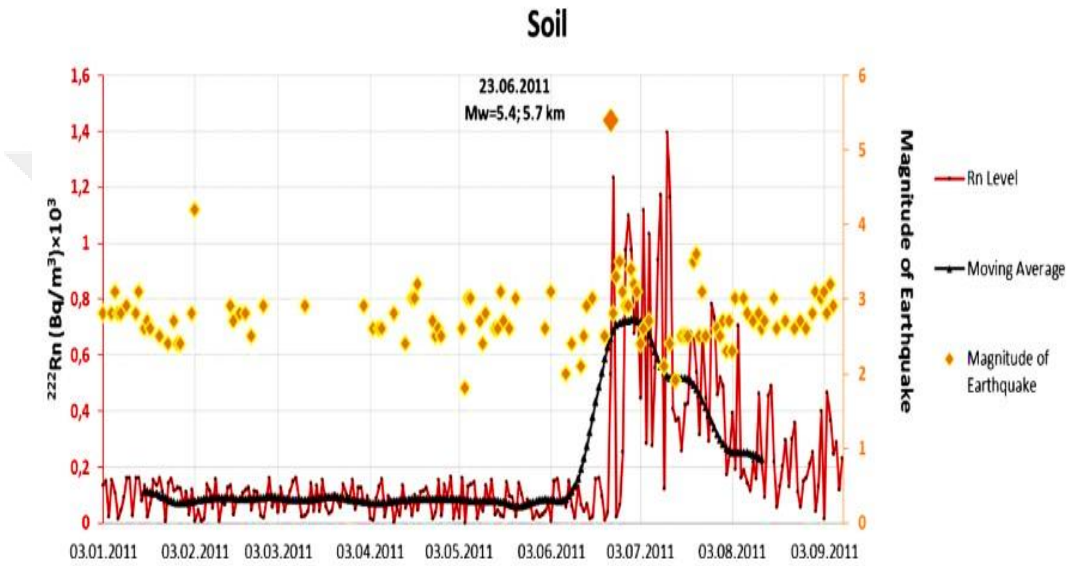

Figure 3. 1. Time series analysis between soil ^{222}Rn concentration, and the micro–macro-earthquakes. Twenty days before the İçme earthquake [218]

3.2. Excremental Procedures

Radon measuring instruments and their decay products are mostly based on alpha particle detection in seismic research. The devices and methods used depend on whether the ways measure radon or radon decay products and the term of the measurements, of which there are three varieties: (i) grab sampling or instantaneous; (ii) integrating; and (iii) continuous [2]. The Luas-cellular method is one of the earliest and most widely used for sampling radon and its decay products in this field [220]. The "Pylon Radiation Monitor" (PRM) can be used for soil samples of radon gas analyses, which includes three main segments. The vacuum water degassing system, a counting monitor, and a vacuum soil explorer, the maximum counting speed of the system is 10^4/s (CPS), the monitor system includes Lucas-type Scintillation cells that can detect radon in water and soil, Lucas cells have a ZnS(Ag), Scintillator, can detect alpha radiation and is a good tool for detecting and measuring radon and their isotopes [218].

4. RESULT AND DISCUSSION

The results will give an approximation of the rapid radon anomaly level from the ground to the atmosphere under the effects of Environmental Factors Based on Radon data were taken from the General Directorate of Disaster Affairs of the Prime Ministry following the scientific agreement we have made so that we can use scientific studies. Historical earthquake data within 100 km of Ekşisu will be supplied from Bogazici University Kandilli observatory. From Erzincan (Ekşisu) data for radon gas and other influential meteorological data analyzed and all calculation carried out by Microsoft EXCEL, I schemed in a three-dimensional graph to demonstrate the relation between RCs in soil and soil temperature in various depths (5, 10, 20, 50 cm) that were implemented underneath of soil, as can be considered radon anomaly directly proportional changed with the temperature in various seasons of years and inversely with low temperature. Similar sentences as shown in Figure.4.1.

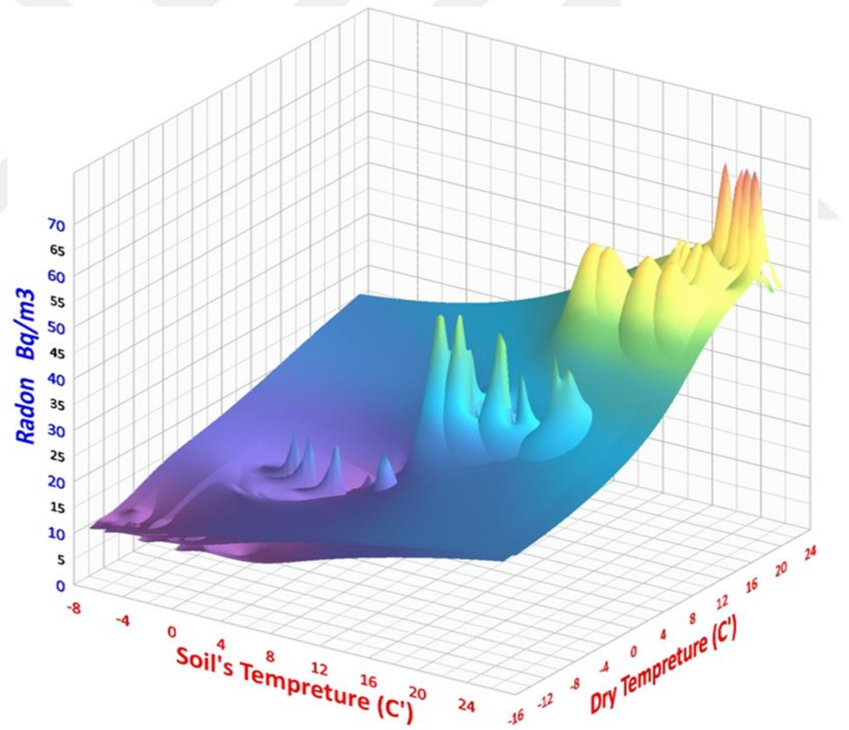

Figure 4. 1. The Graph indicating the correlation between ^{222}Ra anomalies in Erzincan with the dry temperatures, and various depth underground soil temperatures, by our work on Grapher

4.1. Calculations

Time series of ^{222}Ra and vertical ^{222}Rn Activity Profiles in Soil Gas studied and calculated in earlier Literature.

I consider that all parameters were constant and the radon medium was homogeneous, in such case, equation (4.2) will be simplified to mathematic calculating.

The simpler form of one-dimensional diffusion equation (4.1) when, where $I_a$is the radon activity per volume of soil gas (Bq/m^3). All significant parameter knowledge for calculating that we need for the radon soil gas migration mechanism. As can be seen from Table (4.1).

when $D_e < D_\circ$ because of the effective diffusivity is affected by the moisture of the soil, that is why the diffusivity of air will be greater. In other study showed that by increasing the water content of the soil in a long-period test (D_s) changed from 10^{-6} m²/s to 3×10^{-7} m²/s at a depth (z=50 cm) [224].

$$\partial_t I_a = D_s\, \partial_z^2\, I_a\, \lambda I_a + P \tag{4.1}$$

$$D_s = \frac{e_a\, D_e}{e_a + \varepsilon_w + k_w + \rho K} \tag{4.2}$$

Soil radon diffusivity can directly be measured according to equation (4.2) and can be related to soil properties (moisture, pore geometry, and field capacity). like these studies are underway.

(P) is the creation rate of "transportable" Rn per volume of soil gas given by:

$$\mathrm{P} = \frac{\lambda\ f\ \rho\ A_{Ra}}{\varepsilon_a + \varepsilon_\omega K_\omega + \rho K} \tag{4.3}$$

I consider that all parameters were constant and the radon medium was homogeneous, in such case, equation (4.2) will change to the form of equation (4.4).

$$I_a(z) = I_\infty(1 - e^{-z/z^*}) \tag{4.4}$$

Furthermore, to predict our calculating with the D_s the equation is given in Figure.4.2. radon anomaly trend in different depth [221]. The scale depth z* which is a characteristic length over which an Rn atom travels before it decays is related to the soil diffusivity (D_s) by

$$Z^* = \sqrt{\frac{D_s}{\lambda}} \tag{4.5}$$

If (z→∞) in eq (4) it means (I_a=I_∞).it will be the maximum Rn activity at the biggest depth.

In additional (J^{d}) diffusive flux per unit area of the bulk porous medium.at depth (z) can be like equation (4.6).

$$\mathrm{J}^{\mathrm{d}}(z) = -(e_a + \varepsilon_w + k_w + \rho K) D_s \partial_z (I_a(z)) \tag{4.6}$$

If (z= 0) it means at surface (J^{d}) diffusive flux can be calculated from soil to the air, one gets.

$$J^d(0) = -(e_a + \varepsilon_w + k_w + \rho K) D_s \left(\frac{I_\infty}{z^*}\right)$$

$$J^d = -\lambda f \rho A_{R_a} z^* \quad (4.7)$$

Table 4. 1. Average numerical values examined by Nazaroff, W.W.to Calculation of Radon Flux Diffusive From a Representative Surface Soil to the Atmosphere [154]

parameter	symbol	value
Radium activity of soil	A_{R_e}	40 Bq/kg
Emanation coefficient from soil	f	0.25
Air-filled soil porosity	ε_a	0.17
Water-filled soil porosity	ε_w	0.38
Total soil porosity (=ε_a+ε_w)	ε	0.55
Soil density	ρ_g	2700 kg/m^3
Bulk density of soil	ρ	1215 kg/m^3
Sorbed-gaseous partition coefficient	K	1.4× 10^{-5} m3/kg
Radon decay constant	λ	2.1× 10^{-6} s^{-1}
Diffusivity of Rn in air	$D_\circ$	1.2× 10^{-5} m^2/s
Effective diffusivity	D_e	2.6× 10^{-7} m^2/s
Soil diffusivity	D_s	1.5× 10^{-7} m^2/s
Production rate of mobile Rn	P	0.086 Bq/(m^3 s)
Equilibrium activity (z⟶ ∞)	I_∞	40900 Bq/m^3
Scale depth	Z^*	0.27 m
Diffusive Rn-flux to the atmosphere	J^d	68 × 10^{-4} Bq/(m^2.s)
Aqueous-gaseous partition coefficient.	k_w	0.29 (at 15 C°)

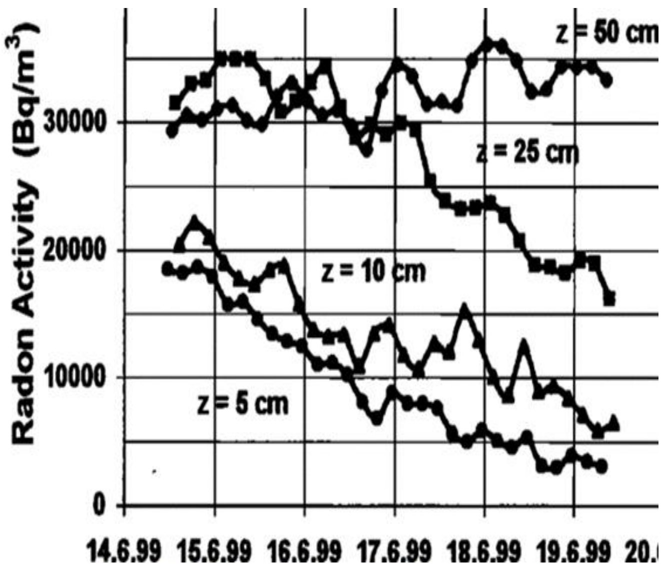

Figure 4. 2. Radon Activity in four depth 5, 10, 25, 50 cm, RCs at 50 cm it stays essentially constant over the period [221]

4.2. Effects of Environmental Factors on Radon Gas Emissions

Temperature: Environmental temperature has a direct effect on radon gas emissions, most researchers believe that as the temperature rises, the amount of soil compaction (formed at low temperatures) decreases, causing more radon gas to escape from the soil. Increasing the soil surface temperature not only expands the air inside the soil and removes it from the ground but also releases other gases and vapors that have been absorbed by the soil particles, there is an inverse correlation between indoor and outdoor radon levels in the air, in which radon level is higher in the early morning with a gradual decrease till noon. outdoor studies have been indicating that radon concentrations increasing by a factor of 10 in the summer compared to winter but its undoubtedly for indoor radon is conversely [222].

Air pressure: Radon gas concentration is inversely related to air pressure; it can be assumed to be a pump located on the soil surface. When the air pressure decreases, radon gas is drawn from the depths of the soil, and conversely, when the pressure increases, radon gas is pushed into the soil.

Rainfall: Radon gas concentrations usually increased during low-rainfall but decreasing relative to heavy rainfall generally, the high concentration of radon gas in the soil first increases and then decreases significantly, it takes several days. This increase may be due to the coating of a soft soil layer; it should be on the ground that prevents radon from being released into the atmosphere, in a few periods after raining, due to the dissolution of radon gas and infiltration of rainwater in the lower layers, Soil the amount of radon gas in the earth's surface decreases.

Wind speed: Wind can push the surrounding air above the ground and releasing radon gas from deeper areas according to the effect of Bernoulli’s law [223].

Radon anomaly data for Erzincan are with its hydrological data and soil temperatures in various distance from the surficial had been used in our study as we can see radon anomalies directly proportional changed by the effect of different season’s temperatures in the different depths of soil from 2007 to 2010, radon flux inclined in with other climatological data parameters as given in Figure 4.3.

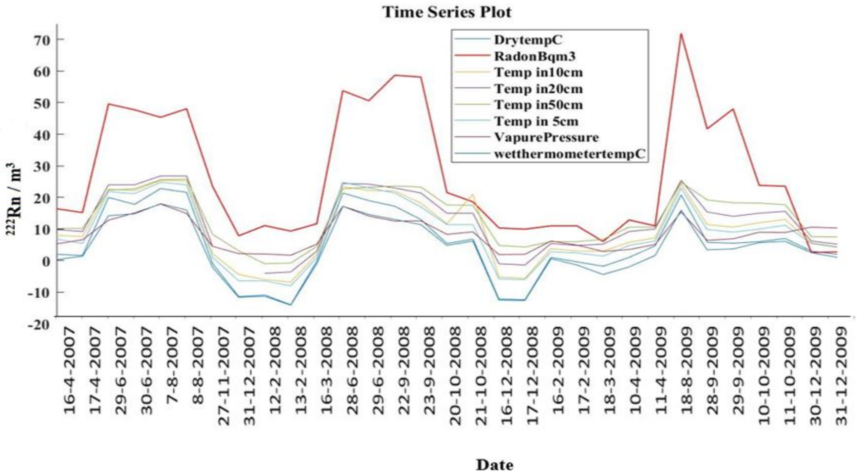

Figure 4. 3. Annual effective meteorological data on Radon gas anomaly are directly changed together such as soil temperatures in (5 cm,10 cm,20 cm,50 cm) and dry temperature, vapor pressure, and wet thermometer temperatures. Graph by Matlab.

The effect of environmental meteorological parameters on RCs can be shown in Table.4.2.

Table 4. 2. Correlation between RCs in soil and some environmental parameters [224]

parameter	Radon concentrations of Soil
Pressure gradient[a]	Positive
Humidity of soil	Negative
Permeability of soil[b]	positive
Temperature of soil	positive
Raining conditions	negative
Tidal Forces	positive

[a]Atmospheric pressure has generally nonlinear effect, but rock or soil pressure has positive effects.

[b]The critical value is 0.1 cm^2/s, it is free-air value.

4.3. Radon Anomalies with Earthquake Magnitude

Based on the approach given data of earthquake and radon anomaly, we created a diagram to compare earthquake and radon anomalies together. We attempted to draw a graph under the data that we obtained from the valid academic website for earthquake data in the Erzincan area between 2007 to 2010. For comparison between both data. Earthquake and radon anomaly together in one graph, as can be seen in Figure 4.4. there is no change in radon anomalies at the same season, but through seismic activities, we have seen the rapid change in radon anomalies as a sign to the precede an earthquake[225]. Due to the specialized characterize of radon gas, the output of the radon rate depends on the seismic activity more than other effects resembling meteorological influence [218]. As a result, of the geochemical investigation recommended that any change in soil RCs not dependent on the presence of basic radionuclides only, the influence of meteorological parameters on soil radon is quantified via correlation coefficients suggesting an insignificant impact [226].

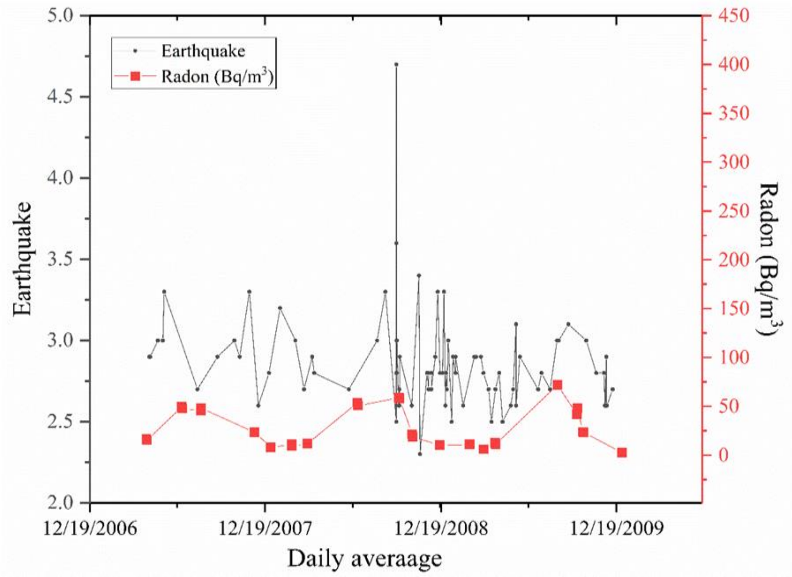

Figure 4. 4. Correlation between RCs anomaly with earthquake magnitude in the Erzincan area between 2007 and 2010

5. CONCLUSIONS

We review here the main points of this thesis, our study area was Northeastern of turkey that known as (NAFZ) in Erzincan district, so that earn a probable relationship between the Radon anomaly and seismic activity to envision quakes between 2017 and 2010.

Radon is one of the heaviest noble gas with highly soluble in water, it has 39 isotopes from ^{139}Rn to ^{231}Rn, all formed by emitting alpha particles from a decay chain of ^{238}U which is expected that the average condensation of uranium in the soil is (35 Bq.Kg^{-1}) or 3 ppm, all thirty-nine radon isotopes are unstable and manmade except three of them are natural radioactive gas such as (^{219}Rn Action,^{220}Rn Thoron,^{222}Rn Radon) that persistently are formed on the alpha decay of their radium parents, (^{223}Ra, ^{224}Ra, and ^{226}Ra) respectively, and most stable among them is ^{222}Rn (Radon) due to its special half-life (3.823 d) that is the last Noble gas that discovered by F. E. Dorn in 1902.

Radon is one of the progenies of radionuclides that originating from terrestrial which is the inert gas because of low reactivity made it being very movable by its recoil energy that is about 86.0 keV, which is the energy source for the flow of new radon gas from the soil grain into its pore space, and this procedure is designated as emanation. Rn is emitted by soil, rocks, and minerals under the layer of the earth's crust, which penetrates various mediums until it eventually getting outside the crust of the earth. by diffusion transmission, to understand significant effective factors on the Radon Concentration rate that has been reported in many scientific publications is the amount of Uranium content or its progeny like radioelements parent or their isotopes beneath the earth's soil and rocks. For instance, primordial radionuclide in the environment including ^{238}U, ^{232}Th,^{235}U. and phosphatic sediments and granitic bedrocks are the richest substance for uranium content. And physicochemical parameters in the lithosphere, for example, based on the physical properties of ground materials such as the spatial distribution of radium atoms in the mineral grain, and the mechanism of radon movement such its direction in the soil is the discharge of radon gas rate to the atmosphere that based on the direction of radon drift during radium decay product(alpha-recoil), and other reasons such as soil porosity, and soil permeability, soil moisture content and soil temperature, The radon emanation factor, and the radon diffusion coefficient in the given material. besides, before, after, and during the earthquake occurrence, fults with higher slip rates are more effective than inactive faults systems for degassing radon gas from the depth to the surface, they will make an easier path for releasing radon to the atmosphere. Because of increasing the recesses and macro and microcracks underlying the earth's crust that made by the stress and strain. Finally, other effects of climatory parameters such as temperature directly the ambient atmospheric pressure rate and precipitations inversely act on radon releasing, and soil grain sizes and moisture of soil inversely act on the radon permeability.

Radon is a single-atom element and is neutral at normal temperatures. Because radium dissolves in water, it can be expected when radium dissolves in water in one place and is transferred to elsewhere. It would because the radon to move away to Produce the original uranium. The concentration of radium in granite is at a high level, however, its value has been reported to be low in basalt rocks. Radon concentration in each region due to differences in geological, climatic, the building materials, and the earth's geology are different. Radon easily escapes from the dry soils or rock of its place of production and enters the water or ambient air but in normal condition. It is possible. The most important source of radon in the environment from the soil, but it can also be produced from water and building materials.

Due to the characteristics of radon gas and its Geogenic, radon gas identified as a tracer for earthquake prediction ,after many investigations in recent dedicates scientist's effort indicated that the radon concentration measurement before earthquake event depended on the seismic activity regions more than other factors, for instance, pressure (by increasing pressure on soil structure, RCs releasing will be decreased due to decreasing pore size between soil's atoms so radon releasing mostly detecting from the upper layer of the ground with minimum pressure), indeed, the meteorological effects (temperature directly has effect on RCs therefore seasonal RCs have various Data as a result of many investigations for observing RCs that the under seasonal fluctuations with less stream in winter and vast stream in the summer span) and the radionuclide atoms include (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) are parents content of radon inside the different mediums (different physical and chemical properties of the medium that are the power supply of radon) in radon releasing processes from the soil to the air.

Time Series Analysis provides great convenience for the detection of different or contradictory situations in the analyzed data. The determination of these data is very important for the correct evaluation and interpretation of the activities of the observed variable. For this purpose, it was tried to interpret the changes by drawing Time Series graphs showing the change of ^{222}Rn concentration with earthquakes. Although noticed there are no big differences in meteorological variables in the same seasons at different dates, it can be said about differences that occurred in the RCs were only caused by seismic activities.

RECOMMENDATIONS

Under our study field that focused on the correlation between the physical properties of radon gas transmission in the soil. We have to review numerous previous studies that related to our studies and because radon gas has unique physicochemical properties it can be used in the various investigation as a tracer for prediction of earthquake or uranium source, furthermore, Radon is deadly for our health because of its radioactive and toxic gas that attack human's lungs and it can be the second reason for lung cancer.

Somewhere that most maximum Uranium progenies would be existing in the soil and lithosphere such as Uranium, Radium, and Thorium. Radon is the single gas in the decay chain of its parent that can penetrate in the dry soil much better than wet soil and it is because of diffusion of radon in the spaces that created after the occurrence of earthquakes in the bedrocks that located in beneath the earth's soil, but by the precipitation spaces between the soil's grain, sand and rock's cracks and micro and macro sizes will be filled and radon gas can be trapping and for a few days it will change to lead or stable nuclide for the reason that the most stable radon's isotopes have only 3.8 days for its half-life. And it is the main reason for radon gas transportation mechanism capability in observing stations for measuring radon concentration in the soil in various depth and temperatures along the faults zone for earthquake perdition or obtaining better results in related investigations.

Many researchers have worked hard on radon, trying to understand its role and why a (relatively small) increase in radon emanation appears to be a pre-earthquake indicator. Most thinking along these lines is by simply assuming crack and microcrack formation, but this is not the answer (or at best a small part of the answer). As the heaviest of the so-called "noble gases", radon is chemically quite active. As Rn atoms diffuse through the soil, they undergo innumerable physi/chemisorption events that delay their diffusion. Before earthquakes, we know that large numbers of positive hole charge carriers are stress-activated deep below, which spread through the Earth's crust and towards the surface. They are chemically, highly reactive/oxidizing. As they traverse the soil, they interact with the physi/chemisorbed Rn atoms, cutting their bonds to the soil substrate and cause more Rn atoms to reach the surface before they decay by alpha emission.

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CURRICULUM VITAE

Saleem Mohammed Shareef JASIM

PERSONAL INFORMATIONS

Birth of Place : **IRAQ**
Birth of Date : 1986
Nationality : IRAQI
Address : **IRAQ-Dahouk**
E-mail : 171114108@firat.edu.tr or saleem.mohammadsharif@gmail.com
Languages : Turkish(B1), English (B2), Persian(C1), Arabic(B1)

EDUCATION

High School : Bakhtiyari, Akre City, Year ,2000-2007

Bachelor : Salahaddin University, College of Education. Faculty, Department of physics, 2011-2012

RESEARCH EXPERIENCES

- ✓ Laboratory Instruments you use (I had been experiencing many instruments in various laboratories during my studies in general physics (Nuclear, Modern physics, Electromagentic.Electronic, Optic, Properties of Matter, Thermodynamic, Laser) laboratories
- ✓ Computer Programming languages available (Grapher, origin, EndNote, MATLAP.)
- ✓ Computer programs you can use (Excel, Word, PowerPoint.)

WORK EXPERIENCE

2013 – 2020: Physics teacher at high school, and other fields in science and mathematics teacher in secondary and primary school

ACADEMIC ACTIVITIES

Projects:

1. International Conference Presentations:

PHYSICAL CHEMISTRY AND FUNCTIONAL MATERIALS (PCFM'18) held on 19-21 June 2018 at Firat University, Elazig-Turkey.

2. Erasmus+ Program Student Mobility for Traineeships (2018-2019):

- ✓ Planned period of the mobility: from [Aguste /2019] to [October/2019]
- ✓ Traineeship title: Calculations of the Potential Energy Surfaces
- ✓ Number of working hours per week: (30)
- ✓ Detailed programme of the traineeship: I stayed in Poland at Nicolaus Copernicus University I've been involved in ongoing research in the Quantum Mechanics Division of Faculty of Physics, astronomy, and Informatics. The main training included the knowledge of quantum chemistry methods needed for calculations of potential energy surfaces in systems important in contemporary physics and chemistry.