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Geopsychology and geopsychopathology: Mental processes and disorders associated with geochemical and geophysical factors

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Summary. Temporal and regional variations in psychological processes have been associated with three geological factors. They are geochemical profiles, geomagnetic variations, and tectonic stresses. In the geochemical domain, copper, aluminum, zinc, and lithium may influence the incidence of thought disorders such as schizophrenia and senile dementia. These common elements are found in many soils and ground water. Geomagnetic variations have been correlated with enhanced anxiety, sleep disturbances, altered moods, and greater incidences of psychiatric admissions. The effects are usually brief but pervasive. Transient and very local epidemics of bizarre and unusual behaviors are sociological phenomena that sometimes precede increases in earthquake activity within a region; they have been hypothesized to be associated with tectonic strain. Many of the contemporary correlations between geological factors and human behavior are also apparent within historical data. The effects of geophysical and geochemical factors upon human behavior are not artifactual, but they are complex and often not detected by the limited scope of most studies.
Key words. Geochemistry; psychology; pathology; geomagnetism; seismicity; psychiatry.

Introduction

Although the idea that geological factors should contribute to human behavior has intuitive appeal from evolutionary and biochemical arguments, empirical support has been less clear. This discrepancy is not unusual for phenomena whose demonstration depends upon factors (in a statistical sense) because they are rarely reflected by a single measure. The available evidence and the conceptual potency of a complex link between geological factors and mental processes are sufficiently compelling to at least entertain the question. This article reviews the concepts, methodological issues, theoretical bases, and empirical support for a causal relationship between changes in human behavior and the three major sources of variance: geochemistry, geomagnetism, and tectonic stress.

1. Psychopathology and soil chemistry

The supposition that chemical constituents within the soil and the underlying bedrock can influence mental processes appears to be based upon two principles: 1) ground water and dependent food sources that are consumed by local residents strongly reflect soil chemistry, and 2) many of the chemical constituents (trace elements) that demonstrate regional variations are also integral components of blood, RNA, DNA and various enzymes. These constituents are effective in microquantities that might be influenced by passive ingestion through the water and food supply.

1.1 The soil concept

The chemical constituents of soil are a function of the

bedrock, the topography, the climate, the local vegetation, and time: how long the soil has been differentiating[38]. Although in some areas, the distribution of rocks can be mapped on the basis of the soil that lie above them, other variables strongly influence the actual chemical composition. Even within the same climatic region, where vegetation is quite similar and the soils are of similar age, topography is also important. For example, the soil on the top of a hill or mountain may be different from the soil on the slope which is in turn different from soil in the valley.

Soil types are usually differentiated in terms of the major concentrations of elements or compounds within various layers (horizons) of soils. One major type of soil contains a predominance of iron oxides and clay or both; they are rich in aluminum and iron. More soluble compounds such as sodium, calcium, and magnesium, have been removed. These types of soils are found in humid, temperate climates. On the other hand, a second major type of soil occurs within drier, temperate climates. It contains larger amounts of calcium and magnesium carbonates. These generalizations ignore the anisotropic distributions of copper, nickel, cadmium, zinc, and other elements that may occur within very local (< 1 km) areas. Yet, accommodation of this local variance may be required in order to reveal a clear relation between behavior and geochemistry.

1.1.1 Zones of goitre and drinking water: a classic example. One of the most convincing links between geochemistry and psychopathology involves the distribution of goitre. It is a thyroid disorder evoked by chronic deficiency of iodine in the diet. Any significant disturbance of thyroid activity can affect mental processes. Hypothyroidism, the most common correlate of goitre, produces intellectual dullness, poor concentration and psychological depression. This condition is associated with iodine poor soils and was presumably controlled by the introduction of iodized salt into the general diet.

A more recent connection between drinking water and goitre again evokes the role of soil chemistry. Gaitin and his colleagues[15] found enhanced incidences of goitre in school children within Michigan, Texas, Georgia, and Kentucky, even though iodine intake through the diet was considered adequate. The link between ground water and goitre was inferred from its incidence in school children who live in the Andes mountains. In this small region of Columbia, unexpectedly high concentrations of resorcinol and the metabolites of phtalate esters, known goitre-producing substances, were found in the ground water. Although these substances are industrial contaminants, they could also be derived from humic organic soil. The goitre-soil water correlation is instructive. It demonstrates that first order explanations for a disorder, such as insufficient iodine, may mask residual cases; they may have multivariate causes. Secondly, the correlation reflects the decreasing capacity to discriminate the presence of natural organic reactions from the pandemic distribution of industrial contaminants.

1.1.2 Methodological issues and problems. The relationship between alterations in mental processes and geochemistry should be the subject matter of epidemiology. Researchers in this area have emphasized clear endpoints such as mortality rather than morbidity; the latter data are difficult to obtain for medical ailments and until recently almost impossible to determine for mental disorders. Large differences in diagnostic practices between specialists from different countries for even the general disorders (affective versus schizophrenic psychoses) have severely limited regional and cross-cultural comparisons. Introduction and assimilation of standardized assessment and diagnostic procedures (such as the Diagnostic and Statistical Manual of Mental Disorders, 3rd edn) by large groups of the mental health community in North America may reduce this impedence. In addition, specific techniques for diagnosing less severe behavioral pathologies, such as personality disorders and panic attacks, are now clearer. There is also a growing awareness that the ultimate prevention of psychiatric diseases of chemical origin will require that psychiatrists around the world consider the possibility of neurotoxic etiology in the evaluation of every patient who displays an illness of unknown cause[34]. There are cases that reinforce this view. One example[88] was an urban woman who displayed nervous and hematological signs of lead poisoning. She was later found to have engaged in frequent geophagia (soil eating); the soil happened to be lead contaminated.

The pursual of the relationship between geochemistry and behavior is probably one of the most challenging problems of the decade. The researcher must deal with both spatial and temporal heterogeneity. In many respects, the problem would have been simpler during the last century when local populations consumed (almost exclusively) food and ground water from the same area. With the advent of modern commercial distribution systems, foods that are grown in one locale can be distributed throughout several continents. A recent example of this complication is the outbreak of insecticide toxicity within more than a dozen states and provinces within North America. The episode was due to contaminated watermelons that were grown in a much smaller area.

The temporal heterogeneity of geochemical sources within ground water and the food chain are rarely addressed in most studies. Usually single measurements from soil or rock samples, taken once from large, disparate areas, are used as predictor variables. Yet contents of well water and ground water can show marked seasonal variations. Source content fluctuations in city water are monitored, although concentrations at distribution ends (that may be contaminated by leaks) are less frequently assessed.

Perhaps the major methodological problem is the growing accumulation of pollutants and toxicants from man-made sources. These may mask or interact with the background geochemical environment. Ironically, there has been a positive feature of contamination episodes. Because they have been local and acute, they have forced awareness of the contribution from ambient geochemistry and have encouraged the development of appropriate methodologies for accurate assessment[34].

1.2 Psychopathology and geochemistry: general rationale

Many of the patients who display thought disorders or behavioral alterations also demonstrate abnormal concentrations of chemical elements within their bodies. The

deviant distributions of soil elements within the blood, brain and hair[71] of these populations are the primary supports for a connection between geochemistry and behavioral changes. However elevations of chemical constituents more frequently reflect alterations in the biochemical mechanisms of the patient rather than the peculiarities of the food and water. Unusual concentrations of dietary elements may aggravate a sensitized or weak biochemical pathway. A number of elements that are found within the soil have been implicated in behavioral pathologies. Well-known neurotoxins will not be considered here.

1.2.1 Copper and schizophrenia. Copper is found in most soils naturally and is artifactually elevated by techniques of water delivery. The average daily dietary intake of copper is about 5 mg[4], however this value varies widely in human populations. About 50% of the copper passes through the liver and enters the circulatory systems via the blood protein: ceruloplasm; it binds about 95% of the copper in the serum. Albumin also binds copper and can transport it (as free Cu) to tissue. Copper is the rate limiting step component of tyrosinase which diverts tyrosine to melanin rather than the typical synthesis to DOPA, the precursor to dopamine. Dopamine is degraded in the presynaptic vesicles by dopamine beta hydroxylase. After release, dopamine is partially degraded by monoamine oxidase. Both are cupric enzymes. The other major copper containing enzyme is cytochrome oxidase which is important in lipid deposition.

The most well-known example of internally mediated chronic copper poisoning is Wilson's disease (hepatolenticular degeneration); it is an inherited abnormality of copper metabolism. Copper to bile transport is reduced and the metal accumulates in the liver and ultimately (via albumin) to the brain. The depositions of copper (and iron) are indicated by the hyperpigmentation of the caudate and lentiform nuclei as a result of the tyrosinase hyperactivity. Motorically, the patients show choreoform ataxias which are also characteristics of dysfunction of dopamine striatal systems. Patients with this disorder frequently present a clinical picture that is misdiagnosed as schizophrenia. The treatment requires control of dietary copper.

A central role of copper in the etiology or exacerbation of schizophrenia has been suggested but not confirmed. Bowman and Lewis[4] have reviewed the long history of the copper hypothesis for schizophrenia. Its primary support is the repeated observations of elevated copper levels and ceruloplasm in acute schizophrenic patients. Elevations in this enzyme also follows ingestation of psychotomimetic drugs by normal volunteers. Copper chelating agents, in particular, d-penicillamine, controls melanogenesis (e.g., changes in skin color) in some schizophrenic patients and also improves their symptoms.

The copper hypothesis is not without flaws. D-penicillamine chelates zinc as well as copper; the metabolism of these two metals are highly related since they compete for many of the same bodily sites. A deficit in one element can evoke a functional excess in the other. When patients on dialysis accidently accumulate excess copper ions in their blood they can display psychiatric symptoms; in general, acute copper toxicity does not generate schizophrenic symptoms. It is the chronicity in psychosis producing copper toxicity that ties copper metabolism to a well-established theory of schizophrenia: the dopamine hypothesis[4].

The antagonism of dopamine by copper over time allows the nigrostriatal (substantia nigra in the midbrain to corpus striatum in the forebrain) dopaminergic system to adjust to the low levels of transmitter by increasing the number or sensitivity of postsynaptic dopamine (D2) receptors. Recent evidence indicates a temporal difference in the changes between receptors within the striatum and within the frontal and temporal cortices[18]. The latter areas are involved with more distinct personality changes.

If copper levels are related to schizophrenia, then discerning the incidence of this disorder within copper variable regions must acknowledge the difference between positive and negative signs[9]. Essentially there are only two basic types of schizophrenia: 1) displays dominated by thought disorders, delusions, and hallucinations, and 2) displays associated with poverty of speech and inappropriate affect. The former type is responsive to neuroleptic drugs (which are almost always dopamine antagonists). Type II is less responsive to neuroleptic treatments and is associated with chronic deterioration and obvious cell death (particularly around the lateral ventricles). Although Type I forms show biochemical abnormalities and Type II forms are more clearly structural, the changes occur within similar brain regions.

Traditional diagnosis and even modern protocols emphasize categories that are not necessarily compatible with or indicative of the two types of schizophrenia. This would limit the isolation of populations whose symptoms may be worsened or triggered by dietary copper. If the copper-dopamine hypothesis is relevant to schizophrenia, then differential concentrations of this element within the soil would be evident in admission data of acute (Type I) cases rather than chronic (Type II) patients.

The critical dosage of copper that might be required to precipitate or promote abnormal behaviors must still be isolated. However they may be surprisingly small. Recent evidence[36] demonstrates that replicable changes in differential white blood cell counts in mice occurs in a dosage-dependent manner that asymptotes at higher than 10 µmoles concentrations. Statistically significant changes were also evident at concentrations of 1 µmole which was only 10 times higher than the concentration of local tap water (control concentrations). Interestingly, the effects required about 10–14 days to peak and returned to baseline levels within three weeks.

1.2.2 Copper deficiency and demyelination. Copper appears to be essential for myelination. Myelin is the lipid rich material that surrounds most of the axons within the brain. Cytochrome oxidase, a cupric enzyme, is important for lipid formation. Impaired function of this enzyme may be responsible for the abnormal lipid compositions of the brains of patients diagnosed with Menke's syndrome. The deficits in copper may be genetically determined defects of exacerbations by combinations of low copper and high zinc within the diet. For example, Campbell and Mills[7] noted that rats maintained on a marginally adequate concentration of dietary copper dis-

played copper deficiency when high levels of zinc were added to the diet.

Relative copper deficiency has been implicated in the most prevalent of demyelinating diseases: MS (multiple sclerosis). This disorder is a collection of variety of myelin-related problems that vary in severity and progression. Classic clinical pictures involve loss of sensory acuity and motoric control. Antecedent symptoms include paraesthesia, blurry vision and transient paralyses (that may be diagnosed as 'hysteric drop attacks'). There are also 'preclinical' diffuse transient behavioral changes that have been described as a general dyscontrol of emotional and cognitive behaviors that sometimes follow traumatic episodes[13].

Although MS is known to occur more frequently in temperate rather than tropical climates, marked local variations occur. High risk MS areas in Norway are located on the eastern slopes of the valleys of southern mountain ranges; adjacent areas are less effected. On the basis of these and other observations, Layton and Sutherland[37] hypothesized that MS risk areas occurred in sectors where the solid rocks and overlying soils contain molybdenum (Mo) but lack the necessary copper and nickel to balance the excess. Of critical importance was the ability for the soil to retain Mo at the expense of Cu.

The Layton-Sutherland model[37] is also instructive for geopsychopathology. They suggest that high risk MS areas might be masked because of cultural traditions for the consumption of high-copper foods. For example, the high incidence of MS in the Orkney and Shetland Islands compared to the Japanese Islands may be due to the consumption of rice by the inhabitants in the latter area. Thus copper-containing rice would presumably protect the population from the conditions that lead to MS.

1.2.3 Aluminum. Aluminum is the major acidic element that is commonly found in acidic soils[26]; Al is lilberated from aluminosilicates of soil clays. Acidification of soils by application of fertilizers releases Al from Al-bearing minerals and acid rains increase Al^{+3} in lake waters. Aluminum accumulator food plants include tea and spices such as oregano. The element is also found within manufactured food sources such as antacids, aspirin, processed cheeses, self-rising flours, and some pickles. Although emphasis has been placed upon the recent introduction of aluminum cookingware, substantial amounts of this element were available in the diet of preindustrial man because of the presence of Al in clay potteries.

The human body burden is normally under 30 mg of Al[26]; yet the daily intake and excretion of this element varies from 20 to 40 mg. Apparently, effective mechanisms exist for the exclusion of Al. Excessive acute increases in Al, such as in the water once used for kidney dialysis, has induced encephalopathology. However the strongest evidence for some role of Al in psychopathology was triggered by reports of accumulation of this element in the brains of people who had died from severe dementias, particularly senility and senile dementia of the Alzheimer variety.

Alzheimer's disease and related senile dementias are associated with profound decrements in learning and memory. The loss of cognitive capacities are sometimes associated with or preceded by psychiatric symptoms such as irritability, emotional lability, paranoid delusions and hallucinations[8]. Senile dementia, indeed senility in general, were and are so prevalent that they were assumed to be normal consequences of aging; this concept is changing.

There are three striking pathophysiological hallmarks of senility. Cores of abnormal proteins that are interspersed among nerve cells are the first major sign. These amyloid plaques contain large amounts of Al and silicon. They occupy areas where large neurons have died[92], particularly within the midfrontal and superior temporal regions of the cortices. Twisted fibers within axons (neurofibrillary tangles) are also more frequent. The latter changes are prominent in the cerebral cortex and around the hippocampus (the 'gateway to memory'), effectively enucleating this structure from the rest of the brain.

The third hallmark is the massive loss of acetylcholine containing cells within the basal nucleus of Meynert, diagonal band of Broca and some septal structures; all are located within the ventral striatum. These small groups of cholinergic neurons provide widespread innervation of the cerebral cortex and hippocampus. Whereas most traditional transmitters are not altered, brains of Alzheimer's patients show drastic reductions in acetylcholine and the neuropeptide somatostatin.

The mechanisms by which Al could differentiately induce an insidious necrosis within acetylcholine containing neurons within such a specific locality are not clear. It has been speculated that these portions of the brain contain key enzymatic reactions that are sensitive to enhanced dietary levels of Al. It is reported to inhibit acetylcholine esterase activity. However, these same areas, particularly around the hippocampus, are characterized by unusual vascular geometries and frequent complications from cerebrovascular diseases. These changes are usually incremental over time and often compensated by alterations in the person's behavior; they are revealed under stressful or novel learning situations. Consequently these problems might remain hidden within a substantial portion of a population.

Enhanced dietary Al may influence other brain mechanisms as well. Several epidemiological studies have implicated aluminum in frank neurological disorders, such as amyotrophic lateral sclerosis. ALS is a fatal disorder that is prevalent in Guam, the Kii Peninsula of Japan and the western lowlands of New Guinea[25]. Al is rich in the soils of these areas, although manganese also shows unusually high concentrations. Like the brains of patients who have died from complications of senility, autopsies of ALS victims have shown increased deposits of Al where the neurons have degenerated.

1.2.4 Other elements. We can expect that an excess or deficiency of almost any trace element might (ultimately) contribute to alterations in mental processes, considering the critical role of metalloenzymes in brain function. Two of the most likely candidates are considered here. The first is zinc. One of the unusual features of the mossy fiber system of the hippocampus is the high concentration of trace metals confined to the terminal fields of these axons[22]. The dominant metal is zinc. Its presence is conspicuous even under light microscopy when hippocampal tissue is visualized by Timm's reaction.

The mossy fibers are axons of granule cells that are the major afferents to the hippocampal pyramidal cells.

Because the zinc occurs within the vesicles of these giant mossy fiber boutons, they are assumed to be involved with transmitter production or release. Deficiency in dietary zinc has been associated with memory deficits and psychiatric disorders. The hippocampal basis of these problems has now been traced in part to defective responses of hippocampal mossy fiber axons. Zinc deficiency reduces the responses of these neurons to successive stimuli, a process that would seriously interfere with information processing and memory consolidation[22].

The other element is lithium. Li is a well-known competitor for sodium and has been implicated in cardiovascular failures. Li is also well known for its treatment of affective disorders, particularly mania. Long-term lithium administration has been reported to increase serotonin release in the hippocampus but not in the cortex[84]; Li facilitates the transport of tryptophan, the precursor to serotonin, into the hippocampus and striatum but not into the cortex. In addition, serotonin binding is reduced and the number of binding sites are decreased in the hippocampus but not the cortex following chronic Li intake[84].

Synergisms occur with Li. The most profound is the occurrence of limbic seizures when cholinergic substances, such as pilocarpine, are administered within 24 h of an acute Li intake that approaches therapeutic levels[23]. Recently we[41] have found that these limbic displays are complex but robust phenomena that can be influenced by the baseline vagotonic condition of the animal. Behaviorally, these states have been argued to generate symptoms that are similar to temporal lobe sensitivity or to a functional hyperconnection in sensory-limbic pathways. Diagnostic clusters would include schizotypal personality disorders (DSM III) that do not involve psychosis.

1.3 Lessons from lead

There are a multitude of well-established neurotoxic elements (that are derived by natural or man-made sources) within the drinking water and the food chain. They include lead, mercury, cadmium, and arsenic. Their detrimental consequences are usually recognized in large, easily discriminated epidemics of neurotoxic illness. As aptly stated by Landrigan and his colleagues[34,35], these episodes represent the visible extreme of a larger more diffuse problem. Sometimes they are blamed on exclusively industrial processes while the geochemical contribution to the problem is ignored.

The neurotoxic substance for which both strong epidemiological and biochemical data are available is lead. It is a particularly relevant element to illustrate in this section since geological sources are often blurred by overlays from industrial products. Lead and zinc deposits are found in limestone that have been exposed to metasomatism, a process in which thermal solutions and magmatic gases have replaced some of the original components of the rock. The distribution of lead has been homogenized in space by industry and consequences of fuel combustion.

Blood levels of above 40 µg of lead per 100 ml have been argued to produce slight cognitive impairment. Blood levels in urban children without known lead exposure may range up to 40 µg/100 ml while the upper official safety limit is between 30–40 µg. David[10] found that the blood of hyperactive children contained a higher lead load than a non-hyperactive reference group. Alterations in nerve conduction have also been correlated with elevated but 'non-toxic' lead levels.

The lead problem is instructive for geochemical epidemiology in general. First, experiments that involve acute, highly toxic concentrations of metals or minerals, may not be valid indicators of the behavioral changes that occur with chronic low level exposures[94]. Secondly, low level, chronic exposures influence more than one neural transmitter system. Synthesis of dopamine in the nigrostriatal pathway is inhibited by lead. Lead levels influence receptor functions in the nucleus accumbens, a brain structure involved with inhibition of behavior (specifically repression of inappropriate responses)[93]. High affinity GABA receptors, the ones associated with inhibition of anxiety by minor tranquilizers, are influenced in a dosage-dependent manner by lead. Winder, Carmichael and Lewis[94] suggest that the accumulation of d-aminolaevulinic acid (ALA), due to the disruption in heme biosynthesis by lead, may produce direct neurotoxic effects. Acetylcholine release is inhibited by lead because it competes with calcium for sites associated with Ca-dependent release.

Third, the uptake of lead even at non-toxic levels is affected by ingestion states. For normal human volunteers, absorption of lead varies from about 10% when it is given with food to 35% when ingested during fasting[74]. Kowalski, Parker, and Persinger[32] noted that food deprivation exacerbated the marginal but significant detrimental effects of 2 ppm of lead (administered through water supply) upon a learning task in mice. These data indicate that when lead salts are ingested in the absence of food (such as episodes of dieting), their absorption and consequences are increased markedly.

Fourth, sources of lead intoxication may lay dormant and become evident only during periods of access. Hunter[24] found that although lead is found in gutter dirt, in older residential areas and along traffic arteries, its access was determined by season. A seasonality in circulating blood levels is even found in adults. During hotter periods and in hotter climates, there is greater mobilization of the body burden of lead.

The lesson from lead can be applied to copper, aluminum, zinc, and lithium. Their excess or depletion may have been pervasive and ubiquitous; because the behaviors may not be discrete qualitatively (or unusual), they may not be detected. Second their relative 'toxicity' may change with the food habits of the population. Third, the true effects of an element may be masked when averages of yearly incidences are used as the primary indicators of occurrence. Fourth, an accurate and valid profile of the microdistributions and concentrations of the element requires more frequent and varied sampling.

2. Geomagnetic variables and mental processes

Geomagnetic variables compose the second factor that has been implicated in geopsychopathology. Because magnetic fields and extremely low frequency (less than 100 Hz) electromagnetic fields easily penetrate human beings[53], they have been the focus of much speculation.

There are four major types of geomagnetic features: 1) the static field and its local steady-state anomalies, 2) geomagnetic storms (and mHz variations), 3) local anomalies that are generated during geomagnetic storms, and 4) the unique Schumann resonance system that exists between the earth's surface and the ionosphere.

2.1 The geomagnetic field: spatial and temporal variations

The earth's magnetic field is in the order of 0.5 gauss (50,000 gamma; 50 micro Tesla). Actual values for the average steady-state field range from about 25,000 gamma near the equator to about 70,000 gamma near the poles. Although subject to secular variation over periods of decades, the major geomagnetic field within an area is relatively stable and can be considered the baseline upon which short-term variations are superimposed[86].

There are substantial variations in the intensity and direction of the earth's magnetic field between areas. Many of these anomalies arise from conductive structures, such as ore bodies, that are buried within the crust. One of the largest anomalies, near Kursk in the Soviet Union, displays background fields (z component) up to 2.0 gauss. Other prominent crustal anomalies[19] that involve electric current concentration occur in Northern Germany, Great Britain and the American Central Plains. Anomalous fields along oceans (coastal effects) may appear 50–80 km inland, especially if there is little disparity between the conductivity of the crust and the ocean[72].

There are two major types of transient changes within the geomagnetic field: 1) geomagnetic storms, and 2) transient local anomalies within the static geomagnetic field during geomagnetic storms. Geomagnetic storms are deviations in the quiet stable background field; the most discriminable variations have irregular periods in the order of seconds to minutes and may continue for hours to days and sometimes weeks. During storm conditions, the horizontal component can vary between 10 gamma to about 1000 gamma (or about 10% of the total field). Several measures have been developed to quantify these changes; among the popular are the Kp, Ap, and aa indices.

Geomagnetic storms are classically divided into three components[56] or phases: the sudden commencement or initial phase, the main phase and the recovery phase. The initial phase is associated with compression of the magnetosphere (presumably due to impact from solar plasma or changes in the velocity/density of the solar wind), resulting in an increase in local intensity. On the ground, the net effect is a field enhancement of between 10 and 100 gamma. This lasts for about 2–8 h. Storms may or may not have sudden commencements. When they occur, the rise times are ordinarily between 2 and 6 min (mode about 4 min) with magnitude changes of between 5 and 20 gamma[44].

The main phase is associated with erratic but general decreases in background field intensities. Average main phase decreases are between 50 and 100 gamma although excursions of over 1000 gamma have been reported for brief periods. This phase lasts for 12–24 h and is followed by a recovery period that may require days to several weeks. Most of the statistical variance in geomagnetic fluctuations are coupled to solar activity and the earth's interface with the solar wind. Clear diurnal variations occur as well as lunar and semiannual variations. The maxima for the latter source occurs in January–February and June–July with the minima in March–April and October–November.

Geomagnetic variation anomalies are the second major transient in the earth's magnetic field; they are brief (hours to days) changes (usually enhancements) of the steady-state background. Those that are of crustal origin arise form redistribution of current systems during a geomagnetic storm[19]. These systems become concentrated in conductive structures, such as sedimentary basins or seawater channels located between resistive continental blocks. Deep basins that are filled with sediments can cause substantial variation anomalies. Porath and Dziewonski[72] reported these anomalies in the Uinta Basin, Utah, the Tucumcari Basin, New Mexico, and the Molasse Basin in Southern Germany. They suspected that transient anomalies, with lifetimes of several days, might exist in many other sedimentary basins throughout the earth's surface.

2.1.1 Relevance to geopsychopathology. Geomagnetic variation anomalies (that can occur for days over several hundreds of square kilometers) and geomagnetic storms are important variables in the study of geopsychopathology. Variation anomalies occur over basins that contain conductive minerals; many of them contribute to the geochemical profiles of the ground water and soils within the region. It is possible that some of the sources now attributed to distributions of soil chemistry may also reflect the persistent occurrence of these frequent but transient events over the life time of the population. Methods of 'dosemetry' for cumulative exposures must still be developed.

Geomagnetic storms in general are reported to be correlated with changes in many forms of animal behavior. Disruption of homing in pigeons[49] and alterations in insect activity are among the most common observations. Because similar disruptions can be produced in controlled laboratory settings, the magnetic component rather than correlated variables appears to be the controlling stimulus[49]. Most animals contain bioorganic iron (magnetite) complexes that appear responsive to background levels of geomagnetic intensity. In fact, if Brown[5] is correct, detection of geomagnetic field intensities may be a characteristic of most if not all life forms. However these responses may only occur within a narrow 'window' of natural intensities[66].

Human beings also detect both geomagnetic field direction and changes in intensity. A continuum of sensitivity is expected. Rocard[78] studied 'responsive' individuals who could accurately discriminate the presence or absence of magnetic field gradients of 0.1 gauss/m; these gradients are frequently associated with subsurface ore bodies or water flow. Other studies indicated that some people could respond to temporal variations of 0.1 gauss/s. Interestingly, this concept and its empirical support were developed by S.W. Tromp[85], and have been essentially ignored or ridiculed[16] without reason. Recently Baker[1] has claimed a 'magnetic sense' may be present in all human beings.

The neurophysical mechanisms by which geomagnetic intensity or its variations might influence human behavior are numerous; there is no clear evidence for any of them[53, 66]. Becker[3] has suggested that the weak (15–20 mV) d.c. polarity differences between the central nervous system and the distal portions of the peripheral nerves may serve as a primitive sensor of geomagnetic conditions. He suspects that it may be involved with some types of nociception (pain). Electrical activity of cells within the pineal gland of pigeons and rats have been shown to be very sensitive to small alterations in the earth's geomagnetic field[80]. Considering the role of this organ in control of circadian rhythms and its massive inhibitory control over the thymus, gonads, and thyroid, this observation may be relevant. Disruption of circadian periodicities can substantially enhance psychological dysfunction.

Magnetite, the most popular sensor candidate for geomagnetic field detection, has been found in the dura mater (covering the brain) of dolphins[96]. These iron rich particles were surrounded by clusters of fibers that appear to be nerve nets. These iron rich particles, which were substantially demagnetized with a few gauss, were found to be multidomain magnetite. Dolphins and whales are suspected to use natural spatial variations in geomagnetic intensity for migration; anomalous highs may seriously inhibit this capacity and contribute to fatal beaching[89]. If similar materials exist in man (and there is preliminary evidence), then changes in magnetic fields of only a few 100 gamma could induce alterations in neural activity.

2.2 Geomagnetic variations and behavior

A clear association between steady-state geomagnetic field strengths and psychopathology would be difficult to demonstrate because of the confounding contributions from temperature and geographical latitude. Analyses of correlations between transient magnetic events such as geomagnetic storms and human behavior are subject to greater control since time rather than space is the critical variable. The incidence of behavioral changes during periods of magnetic perturbation can be compared with quiet control periods within the same population and region[42, 46]. A number of studies have related geomagnetic activity with psychiatric admissions. One of the earliest was reported by von Traute and Dull[83]; they found a small but reliable increase in psychiatric behaviors, including self-destructive acts, within 1–3 days following intense storms. The numbers of behavioral events were about 20% greater than prestorm averages.

The second most convincing study was completed by Friedman, Becker and Bachman[14]. They correlated the admission rates of 28,642 patients from several hospitals during a four-year period with concurrent geomagnetic measures. In order to obtain the optimal window to observe any potential effect, they used 7, 14, 21, 28, and 35 day increments of analyses. Correlations between admission rates and geomagnetic activity were not statistically significant for the 7-day increments. As the increments increased, the correlations increased to a maximum of between 0.22 and 0.34 (median 0.28) at 28-day increments.

Other researchers[73] who removed seasonal and monthly variations from the geomagnetic data (and hence enhanced the smaller daily variations) have been less successful in demonstrating a clear relationship between psychiatric admissions and geomagnetic activity. This suggests that admissions may increase for days to weeks following very large geomagnetic perturbations. Interestingly, unusually large geomagnetic storms (e.g., Ap values more than 100) have been known to desynchronize ambulatory behavior in rats for weeks before baseline levels were regained[54].

Some researchers have hypothesized that electrically unstable brain tissue may be preferentially affected by changes in geomagnetic activity. Very weak current can influence neural gap junctions[33] and some regions of the brain, such as the amygdala in the temporal lobe, are prone to electrical excitability[59]. Rajaram and Mitra[75] reported positive correlations between the numbers of grand mal events and geomagnetic activity over several years within a hospital in India. They hypothesized that the positive correlations were due to a lowering of convulsive thresholds during magnetic field changes. In a clever experiment, Keshavan et al.[30] observed a significant reduction of convulsive thresholds in both human patients and rats during a measured, natural variation of 19 gammas that accompanied a solar eclipse.

Because the perception of pain and proprioceptive stimuli from within the body are influenced by its own opiate systems (endorphins and enkephalins), recent observations by Kavaliers, Ossenkopp and Hirst[29] are relevant. They found that morphine-induced nocturnal analgesia was abolished in mice that had been exposed to rotating magnetic fields for several days. The intensities of these fields were at least two orders of magnitude higher than those associated with geomagnetic storms and under normal circumstances would not be included in this type of review. However, Ossenkopp[51] and his group also noted a reduction in morphine-induced nocturnal analgesia in control animals during a geomagnetic storm (Ap value = 62).

If these data are generalizable to human populations then geomagnetic perturbations may be associated with recondite epidemics of pain and discomfort. In this instance, the normal nociceptive sources of the human body would become more obvious (and acute) because of the lowered pain threshold. Enhanced anxiety and intensification of anxiety-related disorders would follow. The close association between seizure thresholds and the body's own opiates is interesting in light of the reports by Keshavan et al. and Rajaram and Mitra. Limbic seizures may not always be associated with overt convulsions and may be accompanied by anxiety and alterations in thought processes. 'Forced thinking' of specific themes and more dominating delusions are two frequent forms[61] of cognitive changes.

Persinger has suggested that certain periods of quiet geomagnetic activity may encourage non-convulsive electrical changes within the temporal lobe. They would be associated with symptoms that are more frequently associated with patients who have been diagnosed with focal, limbic, or complex partial epilepsy. He suggested that evidence for this link between temporal lobe-related experiences[59] and geomagnetic activity might already exist but be hidden within quasiscientific and parapsychological literature.

Using a retrospective case approach, dates on which intense emotional experiences concerning death and crisis to members of the immediate family or to friends were determined from several data bases. These profound experiences often alter a person's beliefs and have been classified as 'telepathy', grief responses, or schizotypal personality signs, depending upon the researcher's theoretical assumptions[59]. In one contemporary sample[63], these experiences occurred on days when the geomagnetic activity was significantly quieter than the days before or after the experiences. Another sample[65] of these experiences that had been recorded between the years 1868 and 1887 also occurred on days when the geomagnetic activity was quieter than the days before or afterwards. A third study[79] that included other collections of phenomena as case controls demonstrated this effect, although it was not evident for the case controls.

All three studies demonstrated patterns that were similar in temporal form and magnitude. The results suggst that global changes in geomagnetic activity may be associated with specific types of personally, profound and emotional behaviors. Whether or not these experiences are valid or simply manifestations of transient temporal lobe alterations must still be established. The connection between the two phenomena and the propensity for these experiences to occur in clusters during geomagnetically quiet periods, indicates there may be powerful psychoepidemiological phenomena that have been neither accessed nor addressed.

Less acute psychological correlates of autonomic reactivity appear to be responsive to geomagnetic activity. A substantial portion of the variance in subjective mood scores are coupled to day-to-day geomagnetic variation. Persinger and Nolan[67] reported correlations of intermediate strength ($r = 0.40$–0.50) between weekly variability in geomagnetic activity and the numbers of first-aid accidents in a large mining industry. These types of accidents are influenced by psychological and mood-related factors. Because the effect was not obvious using daily analyses, the increased accidents were attributed to exacerbations of job-induced disruptions of circadian rhythms (a common feature of mine workers). Daily rhythms can be altered by geomagnetic storms and are known to influence mood[12].

One of the most labile and critical periods is the perinatal interval; during a few short hours, a multitude of complex enzymatic systems must be modified or initiated. In 1969, Persinger[52] reported increased emotional behaviors in rats that had been exposed perinatally to 0.5 Hz rotating magnetic fields. Both the magnitude and direction of these results were replicated later by Ossenkopp[48]. Operant procedures demonstrated that the behavioral consequences of exposure to these fields were similar to human anxiety[66].

Subsequent to these studies, Persinger and Janes[50] decided to determine if a similar relationship occurred between measures of human anxiety and the geomagnetic activity that was present around the time of birth. Geomagnetic activity was measured by the Ap index and anxiety was determined by the Institute for Personality and Ability Testing (IPAT) scale, an indicator of free-floating, manifest anxiety. In a pilot and a primary study that required two years and involved about 200 university students, weak but statistically significant positive correlations were noted between IPAT scores and perinatal geomagnetic activity the day before the subjects were born. Both male and female subjects who scored above the mean (high anxiety) also displayed stronger correlations between anxiety and geomagnetic activity; the coefficients for the groups ranged from +0.45 to 0.50. Ossenkopp and Nobrega[50] tested the generalizability of the effect by evaluating responses of 13–16-year-old high school students who lived in a different region than the subjects from the Persinger and Jane study. Ossenkopp and Nobrega also used a different anxiety questionnaire (the S-R Inventory of General Trait Anxiousness) while geomagnetic activity was determined by the Ap index. The 77 female subjects showed a weak but significant positive correlation (0.24) between anxiety and the geomagnetic activity two days before birth. When only the high state anxiety female scores ($n = 38$) were used, the strength of the relationship was greater ($r = 0.49$). Male subjects did not demonstrate this effect.

The absence of plausible neurophysical mechanisms by which geomagnetic activity around the time of birth might influence adult human behaviors limited pursual of this effect. This impedence may have been removed. The Delgado group[11] have shown that electromagnetic variations in the order of μT (0.1 gauss) can evoke significant morphological changes in the unborn organism. More recently, Liboff and his colleagues[39] have shown that brief exposures (24 h) to time-varying electromagnetic fields within the μT range affects DNA synthesis. Although these changes have not been linked to human anxiety, they demonstrate that significant physiological alterations may follow brief exposures to geomagnetic-like magnitudes. If a link between perinatal geomagnetic activity and anxiety is correct, then people who are born during days of above average geomagnetic perturbations should also demonstrate greater incidences of anxiety-related disorders.

2.3 Earth resonances

ELF or extremely low frequency (< 100 Hz) electromagnetic fields have a remarkable ability to propagate with very little attenuation within the earth-ionosphere waveguide. In principle, once within the waveguide, an ELF field could circulate indefinitely[2]. This means that large populations might be exposed to the same field patterns for substantial periods. At the lower end of the ELF band, where the wavelength begins to approach the circumference of the earth, a unique phenomenon is produced: the Schumann resonance system. Power spectra of these resonances show maxima at about 7.8, 14.1, 20.3, 26.4, and 32.5 Hz. Amplitudes of the magnetic component are in the order of gammas; the electric components average around 0.1 V/m.

The intensity and number of ELF waves and pulses display diurnal and seasonal variations. In Germany, 9 Hz fields display power peaks between 14.00 and 16.00 h local time and minima between midnight and 08.00 h. The variation is most pronounced during summer months. A variety of ELF propagation anomalies exist and some of them follow geomagnetic storms. There are remarkable spatial heterogeneities in the frequency and amplitude of these signals. Some areas may be persistent

foci for ELF enhancement. Local factors such as water level, mineral content, and topography influence the incidence, frequency, and intensity of ELF fields. Gains from 1 mV/m to 1 V/m can occur between water poor valleys and higher planes with underground water sources. Changes of this magnitude have been noted between two points that were 100 m apart, a marked local variation[66].

2.3.1 Relevance to geopsychopathology. The contribution of ELF fields, particularly the Schumann resonances to human behavior, is based largely on the conspicuous similarities between these wave forms and electroencephalographic (EEG) patterns of the human brain. Konig[31] was one of the first researchers to note the striking morphological concordance of the clear weather (8–10 Hz) Schumann frequencies and human alpha activity (8–13 Hz). He also noted another similarity between poor weather patterns (4 Hz, high amplitude, persistent plateau) fields and the delta activity of the brain. The idea is revived periodically[20].

Konig suggested that these ambient fields might entrain or drive electroencephalic activity in a manner analogous to photic driving of the EEG; the latter is completed by flashes of light within the ELF range. Experimental verifications were attempted by other researchers such as E. Stanton Maxey in pilot studies, but it was Gavalas, Walter, Hamer and Adey[17] who reported the least confounded results. Small but statistically significant shifts were noted in the power spectra of EEG records of monkeys that were exposed to experimental ELF fields.

Ten years ago, the idea of entrainment or any effect by resonance frequency ELF fields should have been (and was) skeptically received. Scalp EEG records are the consequences of millions of cortical neurons and the specific pattern is influenced by skull impedence. In addition behavioral correlates were crude. Recent techniques[47] have shown that specific cognitive conditions involving thought and language are associated with event related brain potentials. They are influenced by the cortical electrical fields in which they occur. They are very likely to be influenced by ambient ELF fields that contain optimal waveforms and amplitudes.

Whereas resonance driving or entrainment of brain electrical activity is expected to be brief, ELF fields might also influence human behavior through other mechanisms. The marked diurnal variation of ELF signals has been considered as a possible zeitgeber for human circadian rhythms. Even their minor disruption can exacerbate psychiatric symptoms and disinhibit socially undesirable behaviors, particularly sexual and aggressive impulses[12]. Jet lag symptoms, such as failures in concentration, are also typical. The strongest support for this supposition is primarily from Wever's[91] laboratory. He reported that human circadian rhythms that began to drift under constant stimuli could be restabilized by superimposition of a 12-h on-off schedule of 10 Hz electric fields within the experimental chamber.

2.3.2 Behavioral changes and ELF fields. Speculative articles abound concerning a relationship between Schumann frequency fields and the occurrence of specific thought disorders or modifications; more extreme theorists have suggested they could be used for psychological manipulation. However about half of the competent experiments with these fields involved human reaction time – at most a crude indicator of cognitive processes. This rationale was based upon its simplicity and early correlational studies between reaction time and natural ELF fields. These studies have been reviewed by Reilly[76].

Michaud and Persinger[45] hypothesized that Schumann frequency field effects should be weak and influence *ongoing* complex cognitive processes. Consequently, they exposed human volunteers to weak 5 Hz, 20 Hz, or control fields during the presentation of a complex narrative that lasted for 3 min. The fields were applied along the plane of the temporal lobes. Subjects that had been exposed to the 5 Hz but not the 20 Hz fields showed significant alterations in the type of memory for the narrative when they were asked to recall it a short time later. Interestingly, 5 Hz but not 20 Hz or 9 Hz fields generate statistically significant increases in reports of relaxation, but not other sensations[43]; that experiment was performed under double blind conditions.

No major correlational study between the incidence of Schumann fields and human behavior is evident in the literature (that is available through computer searches). Ludwig[40] has noted that shielding of VLF fields that occur as ELF pulses can substantially reduce complaints of pain from arthritic patients. In addition, double blind application of fields to volunteers produces quantitative but not qualitative increases in subjective complaints that include the general behavioral dimensions of apprehension-relaxation and concentration-distraction.

3. Tectonic stress and strain

The final geophysical factor involves tectonic strain; direct measure of this condition, which may be derived from both local and far-field stresses, are complicated; they are usually inferred by microseismic activity, subtle crustal deformation and a myriad of often locality-specific geological anomalies. They have been reviewed by Rikitaki[77] and include changes in soil conductivity, earth currents, and radon gas emission (which can collect in basements of dwellings or contaminate well water). These changes may precede a discrete seismic event by several days to months and may occur up to several hundreds of kilometers away from the imminent epicenter.

3.1 Relevance to geopsychopathology

The mechanisms by which tectonic strain might influence human behavior remain to be specified. There is strong evidence that geogenic stimuli can evoke widespread changes in animal behavior before *some* earthquakes. The behavioral changes are described as agitation or panic. A variety of different physical stimuli, known to be associated with tectonic strain, have been reviewed by Buskirk, Frolich and Latham[6]. Electric field changes, low frequency (infra-)sound, ground vibrations, odor (from the release of soil gases), magnetic field changes and high frequency (ultra-)sound are known earthquake precursors. Their magnitudes are also within the range of biological detection.

3.2 Contributions to abnormal psychology

A review of the literature indicates that no one has investigated possible changes in psychiatric admissions or other indices of behavioral dysfunction during periods of

enhanced tectonic strain[62]. Yet their occurrence is expected conceptually. Classes of Fortean events, that include bizarre and unusual environmental and human changes, have been shown to increase in frequency during the months that precede increases in earthquake activity. However this study[55] depended upon limited case sampling from a relatively large area in the central USA.

One frequent but ignored sociological phenomenon involves reports of unusual luminosities or lights; they are popularly labeled as UFO (unidentified flying object) reports. Clusters of UFO reports within a small area (100–1000 km^2) display striking epidemiological characteristics. There is a quick increase in the numbers of reports followed by an asymptotic period when the range of bizarre behaviors suddenly widen. Then the phenomena cease after a few weeks or months. Sociological changes within a community during these periods can be substantial and even approach panic.

Analyses of a number of these episodes by Persinger and Derr[68–70] indicate the presence of a seismic factor. These reports tend to occur days to weeks *before* increased earthquake activity within the region; the frequency of the reports are functionally related to the amount of seismic energy that is released. The area of inclusion depends upon the morphology of the crust and local fault boundaries. Strong ($r > 0.70$) correlations between imminent seismicity and these behaviors have been shown for episodes that occurred in the Uinta Basin, Utah; Yakima, Washington (before the eruption of Mt. St. Helen's) and Carman, Manitoba. A similar pattern is expected to occur or to have occurred in any of the zones that are presently under compressional strain as defined by the conterminous maps of Zoback and Zoback[95]. Many of these areas are sedimentary basins that are prone to geomagnetic variation anomalies[72].

The tendency for unusual behaviors to increase weeks to months before earthquakes within a region may have been more prevalent than suspected[90]. Historically, the incidences may have been masked by contemporary explanations for the Unknown[58]. For example, 'invasion mania', observations of 'odd airships' and general behavioral pathology were epidemic in the central-eastern USA during the year 1897[27]. The episode lasted for about three months and was terminated immediately by the strongest seismic event in the recorded history of the area. This observation is not anecdotal. Historical analyses of these behaviors within Western Europe[60] for the years 1870–1910 demonstrated a strong coupling to seismicity. All of these analyses suggest the occurrence of fundamental pervasive changes in human behavior within regions that will be subjected imminently to seismic activity.

4. Considerations and suggestions for future research

A number of strategies might be used to determine the degree to which geological factors contribute to behavioral pathology. The first step is to emphasize morbidity data and different categories of behavioral patterns rather than mortality (e.g., suicide) measures. Newer and more homogeneous diagnostic procedures are now available; they will soon be supplemented by chemical markers. Greater emphasis can be placed upon less severe but more frequent behavioral dysfunctions such as personality and anxiety disorders. Many of them are associated with subclinical changes in brain structures, such as the temporal lobe[59] and ventral striatum, that are sensitive to variable concentrations of geochemical elements. The use of epidemiological models in relating psychiatric incidences to geochemistry has been suggested[87]. Studies in which matched controls are compared to a population of patients, are still useful. To be valid, however, appropriate and *repeated* measures of water and soil chemistry of the subjects' environment must be included. Areas suspected of geochemical anomalies are obvious candidates, particularly where residents who consume reservoir or treated water live near those who still use private wells. Once again this type of research will require the difficult but necessary interaction between geochemists, psychiatrists, psychologists, and epidemiologists.

Psychological variables are also important as independent rather than dependent variables. Several studies[81] have shown correlations between the distributions of trace elements within the water supply and the occurrence of heart diseases. Yet coronary heart diseases are influenced by recurrent thought processes. Individuals who display persistent patterns of time urgency, aggressiveness, hostility, and cynacism[21] (Type A individuals) are more likely to develop heart disease. They may respond differentially to the presence of trace elements in geochemical profiles than people who develop heart problems from other sources.

The contribution of geomagnetic storms to human behavior is more easily demonstrated[57]. However it appears critical to utilize the appropriate temporal increment of analyses (which may not always be days). In addition, the response of a population to a singularly intense geomagnetic storm may continue long after the perturbation has ceased. Researchers[73] who have failed to address these temporally heterogeneous relationships between geomagnetic activity and the latency and duration of responding have also failed to demonstrate any effects. Epoch analyses, which assume catastrophic or qualitatively dissimilar occurrences within a temporal continuum, would be more appropriate methodology.

Unlike geochemical factors which are dominated by heterogeneity of spatial distribution, geomagnetic factors are unevenly distributed in time. This allows a unique opportunity to measure changes in behavior within more or less the same space and population. It also challenges the researcher to obtain innovative methods of measurement. Within the last ten years, particularly in major cities, systematic records of telephone calls to crisis hotlines and other psychological emergency services have been maintained and baselines are available.

Any consequent research between geomagnetic fluctuations and the indices of inferred psychological processes[64] must address the strong interaction between crustal conductivities, such as sedimentary basins, and the transient occurrence of geomagnetic variation anomalies. Their existence means that people within these areas are exposed periodically to substantial alterations in local magnetic field strengths. They are within the same magnitude range as those that have been correlated with alterations in the behavior of marine mammals. Many anomalies occur in areas where the population is not mobile and there is a surprising frequency of 'clusters' of behav-

ioral epidemics. However, there has been no central registry for maintaining these records.

Many psychiatric hospitals and social agencies have records that cover decades. Although sampling problems are difficult, they are not impossible to accomodate. The largest problem has been to access archived (often misplaced) files. This cumbersome practice is gradually being replaced by computer-based data files. There should be enough data in some areas to discern any changes in psychological disturbances that may precede the increase in seismic activity within a region. The validity of these effects could be determined by using communities around which there was no obvious tectonic activity as case controls.

Finally, one source of behavioral data that can be used to determine the effects of geophysical factors may have already been recorded for years. They include historical newspapers and the myriad of forgotten 'natural observation' books that lay on dusty library shelves. There is a general tendency to dismiss these accounts as archaic or prone to gross sampling errors. However many human activity patterns (such as the diurnal variations in birth time), that were 'discovered' this century were also obvious in the last[28]. In fact, scientists of the last century and early 20th century were meticulous record keepers. They also gave specific dates for the occurrences of specific pathologies. One example is Spratling's[82] text on epilepsy. Unlike contemporary ictal events that are superimposed on complicated medicational regimes, Spratling reported accounts before the development of effective antiepileptic drugs. They may mask intrinsic features of the natural phenomena.

This review has considered the general factors in the geological environment that have been shown to be correlated with alterations in mental processes and behavior. One can expect even more striking discoveries as this area is subjected to analyses by contemporary methodology and computer software. This progress will require greater usage of multivariate analyses and less conceptual bias against the role of global factors in local behavioral incidences. There is a profound link between human behavior and geophysical and geochemical stimuli. However the correlations appear to have been concealed by their spatial complexity and transience.

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Soil and congenital malformations

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Introduction

Congenital malformations are just one manifestation of reproductive failure which can be induced by environmental factors. The complete spectrum of effects includes sexual dysfunction, chromosomal abnormalities of the germ cells, sperm abnormalities, sub-fecundity, maternal illness during pregnancy, early and late fetal death, intrapartum and neonatal death, low birthweight, altered sex ratios, multiple births, congenital structural abnormalities, functional abnormalities, infant death, infant morbidity and, possibly, childhood malignancy[8, 24]. Although many countries have systems for reporting congenital abnormalities, these are not wholly effective for a number of reasons. Firstly there is the problem of diagnosing and defining lesions: with gross defects such as neural tube defects this is straightforward but with less distinctive abnormalities categorisation is more difficult. Moreover, associated or multiple abnormalities may not be completely recorded although, as in the case with neural tube defects, such information is important in epidemiological studies of possible associations[17, 20]. Another disadvantage with the recording of defects at birth is that many, such as those of the heart and cardiovascular system may in fact not be detected until later in childhood, and unless specific studies are made it is conceivable that many abnormalities of immune, neurological and intellectual, and endocrine function may be missed completely[20].

No stage of fetal development is protected from potential environmental insults and even the pre-implantation trophoblast has the capacity to metabolize some xenobiotics. After implantation considerable cellular differentiation and migration occurs as the fetus assumes the recognizable morphology of the adult. In man this stage of organogenesis occupies most of the first trimester and blends into the period of histogenesis during which extensive growth and functional maturation of the organs proceeds.

All of these developmental stages can be disrupted and the principles of teratology have been summarized in this manner: 1) susceptibility to a teratogen can be influenced by genetic background; 2) the teratogen or its metabolic sequelae must reach the fetus; 3) the effects of a teratogen are dose dependent and may cause fetal death; 4) the teratogen's effects depend also on the developmental stage of the conceptus; and 5) different teratogens may have different specific effects which nevertheless result in similar morphological and functional anomalies[21]. Additionally, in the broader context the possible ability of some environmental insults to induce genetic and chromosomal abnormalities should not be neglected[20].

Soil is, of course, an important source – through water, plants and animals – of many of the inorganic elements which are essential for life[10, 45]. In some areas, either as a result of anthropogenic activities (mining, smelting, reservoir construction, etc.) or of local geochemical anomalies, excessive quantities of both essential and non-essential elements may enter the food chain and influence human health[10]. Thus the effect of soil on human reproductive function may arise from both deficiencies or excesses in the abundance of inorganic elements; or, more specifically, it may be the relative amounts of these elements which could be important in influencing human health and reproductive function. The possible nature of the latter effects can best be assessed from experience derived from animal models and from the management of farm livestock.

Effects of elemental deficiencies

The range of defects which has been observed with deficiencies of essential elements are summarized in table 1[15, 29, 47]. Probably the most important problems in practical terms arise from inadequate supply of copper, selenium, iodine and zinc. Geographical regions in which these deficiencies are known to affect livestock would be appropriate target areas in which to seek possible and analogous effects on human reproduction. The effect of copper deficiency on the fetus is particularly apparent in ruminants. Affected regions include Western Australia, Southern Africa and many sites in the South American plains as well as focal sites throughout the world. Calves, lambs and kids manifest the neurological lesions most obviously but often have associated defects in their hair, haematopoiesis, myocardial function and skeleton. It is apparent that the underlying copper deficiency arises from a relative excess of available molybdenum in the soil and forage which in turn can arise from a relative alkalinity of the soil, and poor drainage; molybdenum interacts with copper and sulphur to form insoluble precipitates