Define what is meant by the <u>Lithological</u> and <u>Structural</u> <u>properties</u> of rockmass.
For Structural and Lithological properties, explain their <u>origin</u> and i<u>mpact</u> on the <u>geomorphic performance of rock under stress</u>.

"Changing the jars for the soldier in white was no trouble at all, since the same clear fluid was dripped back inside him over and over again with no apparent loss...Changing the jars was no trouble to anyone but the men who watched them changed every hour or so and were baffled by the procedure. 'Why can't they hook the two jars up to each other and eliminate the middle man?'" (Catch-22, Joseph Heller)

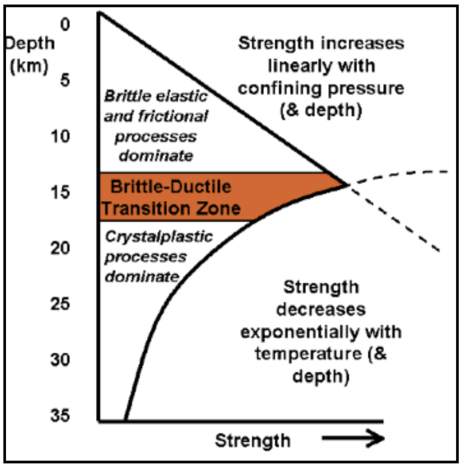
Somewhere amidst the banal slurring of the satirist lies a dormant truth about the nature of modern geomorphology. The Earth as an object of Time immemorial's curiosity, can be regarded much like the dialysis-machined, bandage-woven Texan of Heller's world. One often wallows in a paralysis of unknowns with both, baffled by their inner workings, teleologies, cosmologies, raison d'etre's. To grasp a holistic knowledge of such enigma, the 'mystery beneath the bandage', one has to progress through the oft-stodgy process of fragmented observation. From humble beginnings, one can visibly glean that both are shaped by active and passive inputs and outputs, the soldier in white, submissive to the foreign fluids, yet active in his endogenous secretion; the Earth, submissive to an erosive climate; yet active in its churning tectonics. Yet beyond such visible observation is unchartered and fruitless desert and to progress beyond the drought one has to enter into the realms of Socratic speculation; toward the paradigm shifting, upon-a-time absurd thoughts: Yossarian and his 'Middle Man'; Wegener and his plate; or Lovelock and his Gaian affair. Science is driven by refutability and truth percolates through a continuum of disproved hypotheses, such that the outlandish is never undesired (provided they regard Hutton's "Uniformity of Law").

The original slur of Yossarian appears immorally saturated, like the phlegmed beard of an illiterate undertaker, yet on closer inspection his hypothesis holds an authentic rational basis; that of the paraplegic and his right to die at peace. Similarly the original slur of Wegener, that the Earth is founded upon perpetually shifting plates, appeared foolhardy yet is now regarded as scientific truth evidenced in the burning chasms of the asthenosphere. Geomorphology, the study of the physical land-surface in its form, processes and history is thus a fluid and dynamic discipline whose pillared forefathers introduced the philosopher to the pragmatist. As Jacobsen contends, Earth Systems Science evolved as a geographical paradigm in the post-war climate, a growth that "coincided with the growth of capitalism and industrial mercantilism in northern Europe", in essence a sort of second Renaissance in which the old persuasions of Godly creationism and Neptunism were dispelled and replaced by the rationalities of uniformitarianism and the 'present being the key to the past.' One recalls the optimism of Emerson clamouring, in his deep Bostonian tones, for independence from the past and its lifeless "dry bones" (Nature) towards a more active truth-seeking: 'the Sun shines today also", a fitting axiom for the Uniformitarian. The Sun shines today and the earth burns deep to continue causing great global disfigurements of the Earth's landscape, most notably through the denudation and tectonics that affect rockmass. One is dually concerned as to the macro-forces which underlie such change, and to the micro-factors - the lithologies and structures - that determine the geomorphic performance of igneous, metamorphic and sedimentary rock under stress.

In deconstructing the interrelationships between geomorphic stress performance and lithological-structural process, one must firstly define rockmass and its constituent parts: “Rock masses are far from being continua and consist essentially of two constituents: intact rock and discontinuities (planes of weakness).” (Edelbro, 2003). The term ‘discontinuities’ refers to the structural breaks which often have zero or low tensile strength, whilst ‘intact rock’ refers to the coexistent unfractured blocks that are placed between these discontinuities. The intact rock may consist of one mineral but more commonly are crystalline amalgamations of several. In the study of rockmass movement, lithology refers to the “macroscopic character...determined by its geochemical (mineral) and mechanical (particulate) components and related structures” (Smithson, Addison & Atkinson 2008). Structure is a tangential concept but with a more specific focus on the geological motion-mechanisms and internal discontinuities of the rockmass. Structure engages in specificities of the joints, bedding planes, fault lines and fractures associated with tectonic and porous-erosive movement within the rock, whereas lithology engages in the analyses of grain and particle size, particle shape, fabric (orientation and packing) and physical and chemical compositions.

The formations of distinct lithologies and structures are dependent upon global processes of tectonics, weathering and erosion. In a specific context weathering is regarded as the “total of all the sub-aerial processes acting at or near the earth’s surface whereby rock undergoes physical disintegration and chemical decomposition.” (Strahler) Erosion, often a corollary of weathering, involves the transport of the loosened, weathered product, often by rain wash and wind into the ocean, a sediment sink. Essentially, weathering is static decay by chemical, mechanical and physical agents whilst erosion is the dynamic destruction of landscape by agents simultaneously moving and removing the debris. Together, erosion and weathering are termed denudation, the continual stripping down of rockmass once it is exposed to the “significantly different hydrothermal and mechanical conditions [of] the land surface” (Smithson, Addison & Atkinson 2008)

The significance of this litho-structural interface is largely evidenced in the motions of stress and strain in a rock mass. According to Huggett: “A stress is any force that tends to move materials downslope.” Furthering his definition, it is a directional force acting on a rock per unit area, and encompasses four types: uniform lithostatic stress (a constant force); compressional (lateral crushing); tensile (lateral stretch) and shear (sliding rupture). Such forces acting upon rockmass “originate internally [tectonically] through volumetric changes, associated with heating, cooling, chemical reactions and the circulation of fluids,” (Smithson, Addison & Atkinson 2008). Stresses also originate externally via weathering and erosional processes. Both intact and discontinuous rockmass hold responsive capacities to these endogenetic and exogenic stresses. Resistance is measured by hardness (often using a Shmidt hammer) and resistance to abrasion; it is “the sum of internal strength properties capable of resisting tensile, compressive and shear stress. The intact strength, on the other hand, is more exclusive and is a measure of "the peak strength of a rock mass capable of resisting stress, that excludes discontinuities" The rendering of intact strength problematic is precisely because the strength of a rockmass relies often wholly upon the strength, or in most cases, weakness of the discontinuity.



The strength and behaviour of a rock mass is largely controlled by the nature of its discontinuities; discontinuities, and their interior properties such as roughness and size, lower the strength of the rockmass. Rockmass tends to fail along existing weakness planes rather than develop new fractures within intact solid rock. Stress fractures originate from several processes: tectonic joints form during deformation episodes "along planar structures such as faults; in which the vast bulk of intervening rock mass may remain intact, even if relocated en masse." (Smithson, Addison & Atkinson 2008); release joints form during the reduction in load as rock is uplifted and erodes to spread laterally at the surface; cooling joints form as isotropic, polygonal columns when magma cools in the foreign physical and chemical conditions of the earth's surface. Stress-creation also occurs and is catalysed ("a means to an end") from exogenic, atmospheric processes. In abidance with that Penckian vision of simultaneous uplift and denudation, exposed rockmass is rapidly weathered and eroded, such that its strength is reduced by "the generation of internal stresses or the alteration of geochemical properties." Joints are effectively prised open via the physical and mechanical processes of heating, hydration, salt crystal growth and elastic strain release. One such example is 'cryofracture', a process that occurs in response to the 9% expansion of water on freezing. In open fractures voids absorb the stress, however on repeated freezing and thawing fatigue failure eventually occurs. Large diurnal temperature changes assist this erosive-deformational process.

The existence of discontinuities create anisotropy (unequal forces) in its response to loading and unloading. Furthermore their higher permeability, reduced shear strength along planes, increased deformability and negligible tensile strength create avenues for the destabilising effects of weathering and erosion. Discontinuities, in fact, "render rock mass mechanically and hydraulically defective", they are "planar partings [in which] the cohesive or intact strength, is momentarily interrupted or lost" (Smithson, Addison & Atkinson 2008) Shear stress predominates in geomorphic processes and often causes strain when it forceably overcomes the shear strength of the rockmass. A calculation of rock strength and mechanical performance is particularly important in engineering; the rock is described "by its strength, stiffness, anisotropy, porosity, grain size,shape and fracture occurence".(Priest, 1993). Strain is regarded as the rock's mechanical response to any stress that exceeds its shear strength; it is the physical change in shape or size resultant from the stress-deformation. Rocks only strain when placed under stress and there are several types of strain that occur dependent on conditions of temperature, pressure and internal rock compositions: elastic (non-permanent deformation) , brittle (permanent, fractured deformation) and ductile (permanent, non-fractured deformation). Over small differential stresses, rockmass performs elastically, thus when the stress is reversed the rock returns to its original shape; the sudden jolt often creating shallow seismic tremors. Brittle strain response often occurs near the Earth's surface, when a differential stressgreater than the rock's yield strength causes the rock to fracture. Ductile deformation occurs at high temperatures, often deep in the lithosphere and under enormous lithostatic pressures such that it is near impossible for rock to fracture.

It is in effect a brittle deformation that has been made malleable by the extremes of heat and pressure to the extent that it behaves viscously and flows. The strongest layer of the Earth's crust occurs in a geological band 13-18km in depth; the brittle-ductile transition zone. At this depth ductile deformation occurs; the brittle strength of a material is increased by lithostatic pressure, whilst the ductile strength is decreased by the high temperatures. Lithologically-different rock have differing relationships between the rate of deformation (strain rate) and the applied stress (shear stress). The Mohr-Coulomb equation is pivotal in the study of geomorphic performances under stress, such that even the predictions of future landslides are possible. The Mohr-Coulomb provides an algorithm for the peak strength of a rock mass that is capable of resisting shear stress. It illuminates the point of imminent rockmass failure when "the balance between force and resistance - the limiting equilibrium" is breached. (Smithson, Addison & Atkinson 2008). The criteria originated from the combined efforts of a man of Germany and a Frenchman, Christian Mohr and Charles-Augustin de Coulomb, geological futurists of the 18th and 19th Centuries.

$$\tau = \sigma \ \tan(\phi) + c$$

Their combined criteria comprises of internal cohesion, friction strength and normal stress as the variables. T = Shear stress; o = Normal Stress; c = Cohesion; Ø = Angle of internal friction.

Such an equation encompasses the three components of shear strength that are resistant to stress - cohesion, the "electrostatic and magnetic bonds between minerals, cement and water"; normal stress, the anchoring weight; and friction strength, the generated gravitation strength at mineral contact points, that is determined by the rock's texture and packing arrangement. This last point is paramount in understanding the differing geomorphic performances of the three lithological types. A mathematical research undergone by Smithson, Addison and Atkinson reveals that Igneous rocks have greatest shear strength; the plutonic-intrusive granite having the highest cohesion of 56.1 MN m-2; friction and residual angles. Extrusive igneous rock, slightly less strong reveals the pivotal relationship between the abundance of discontinuities having originated in rock formation and the level of shear strength. With polycrystalline metamorphic rock middling the geotechnical parameter - and notably having least cohesion (22.9) due to its polycrystallic roots - it is clastic sediment which reveals the lowest shear strength, a facet attributable to its greatly fractured structure, and porous-weathering prone lithology.

Lithology gives rise to the three broad descriptive rock types: igneous, metamorphic and sedimentary. In geology, “rock type is defined according to the abundance, texture, mineral composition, mode of formation and degree of metamorphose” (Loberg, 1993). Igneous rocks are large rocks of generally high strength; sedimentary rocks, softer minerals, often anisotropic; and metamorphic rocks, which vary greatly in properties, composition and structure. Each rock type is distinctive for its physical, chemical and crystallographic nature. Igneous rocks originate from the magma of the asthenosphere (molten peridotite) and form by a process of solidification (lithification: “hardening) as successively lower temperatures through the lithosphere give rise to fractional crystallisation and the formation of solid minerals. The most common igneous rock are granite, basalt and gabbro. Igneous compositions are fundamentally of silicate and felsic minerals; quartz-rich rock being silica over-saturated and feldspathoid-rich being silica-undersaturated. As F.G Bell contends: “The rate and location of cooling determine its mineralogical evolution and eventual rock character.” The two major sub-categories of rock are intrusive and extrusive. The former are created by a process of lithification within the crust and surrounded by country rock; hypabassal if formed relatively near the earth surface and abyssal if formed in deeper plutonic chambers. The cooling process is relatively slow and thus intrusive rocks are coarse grained and have large silicate grains, often visible to the naked eye (phaneritic).

Extrusive rock forms by lithification and diagenesis exterior to the earth’s surface, they thus cool quickly on exposure to the foreign atmosphere. The crystals are finer grained than intrusive crystals and vary in particulate size dependent upon the volcanicity and viscosity of the initial eruption. Obsidians form from explosive, pyroclastic flows that rapidly prevent the formation of crystals (aphanitic); whereas viscous rhyolite, ejected in the same pyroclastic eruption, lithify at slower rates and thus contain relatively larger crystalline formations at more limited spatial extents. The formation of igneous rockmass at the surface occurs most commonly at mid-ocean ridges, subduction zones and fold mountains. Structurally igneous rocks often contain parallel horizontal planes formed through the post-denudation expansion of rock that is upon a time nascent to the atmosphere. Jointing occurs, formed by contraction of rock as it cools and by igneous intrusions that disrupt surface rock, Giant’s Causeway in Northern Ireland being an example. Such joints are potential zones of weakness for weathering and internal strain, yet compared to sedimentary rocks, “the joints are mostly tight, thus the permeability and storage capacity is low.” (Bell, F.G) Extrusive rocks, as they are formed by the consolidation of magma on the earth surface, and are exposed to the weathering agents more then intrusive rocks, contain many more discontinuities in them, often larger and more permeable and thus more greatly exposed to the freeze-thaw, rock-weakening process.

Metamorphic rocks form through mineralogical and structural alterations in igneous and sedimentary rocks. The original rock (protolith) undergoes a metamorphosis due to “temperatures or pressures high enough to cause recrystallisation of component minerals” (Bell, F.G). Metamorphic rocks, such as schist and marble, often result from prograde, contact metamorphism in which the increasing pressures and temperatures of an igneous intrusion upon country rock cause large-scale chemical and physical alteration. Although joints may survive metamorphosis, often the fresh melting and fracturing will destroy them. However, metamorphic rocks may contain their own lines of weakness, such as the cleavage lines seen in slate. Post-crystallisation metamorphic rocks are often fine-grained with a foliated texture and patterns of strain (plastic deformation), resultant from the differential stresses of metamorphism. These distinct structural strains (schists) often equate to susceptibility to one-directional fracture and decay as homogenously-aligned grains facilitate the failure (a facet that applies to all fissile rocks).Crazing, a process of extensive microfracturing often occurs in basalt-based metamorphic rock that is exposed to moisture in its schists. Metamorphism often occurs deep within the orogenic belts created in the folding and faulting, collision of continents, before uplift brings the morphed rockmass to surface. “The cumulative effects of six to eight global orogenic episodes have created complex metamorphic belts around the cores of contemporary and older orogens.” (Smithson, Addison & Atkinson 2008)

Sedimentary rocks are “the unconsolidated detrital and dissolved remains of other rocks and organisms.” There are several types of sedimentary rock; clastic sediments are “formed by [unstratified] particles broken off parent rocks” and indurated (Smithson, Addison & Atkinson 2008); chemical sediments, by the precipitation of dissolved salts and silicates; and biogenic sediment, formed from organic detritus. According to the sedimentary origin and longevity of lithification, each sediment varies in its ability to resist weathering and erosion; the weakest being carboniferous limestone and chalk. Sedimentary basins, in particular terrestrial basins, form after a period of transport, suspension or solution, when particles agglomerate as a result of long-term compressional forces. This is known as diagenesis, a process that “affects sediments after their deposition and during burial” which excludes “the effects of tectonism and metamorphism; compaction [being] the main physical process.” (Hancock P.L. & Skinner, B.J, 2000) During diagenesis, water is gradually expelled and sediment is laid down in parallel bedding planes. A stratum of sedimentary rock compressed into such planes reduces the void space between grains, increasing frictional and vertical cohesive strength; however lateral joints proliferate within the planes to provide “avenues of weathering and erosion.” Lithologically, the bonds between sediment grains are provided by the cement or matrix formed during the lithification process, rather than by interlocking grains. Thus the diagenetic process holds pivotal influence in not only the strength and elasticity, but also the density and porosity of the rockmass. A good example is mudstone such as shale, found in regions of high diurnal temperature variabilities. Their durability is determined by “the degree of induration, fracturing, grain size distribution and mineralogical composition.” This in turn affects the rock’s susceptibility to slaking, a form of moisture-driven strain that often occurs to increase the scale of existing fractures. After brief periods of carving wetness, dessication occurs to draw air into outer pores as high suction pressures develop. The rapid change in weathering process leads to further stress in the rock fabric, and greater potential erosive slaking, a positive feedback effect. Furthermore “the presence of water in any slope substantially reduces shear strength by removing the cohesion between intact blocks.” (Smithson, Addison & Atkinson 2008).

In conclusion, the lithological and structural properties of a rockmass are significant determinants in the geomorphic performance of rock under stress. Between igneous, metamorphic and sedimentary rocks, their differing mineralogical, textural and structural properties appropriate to cause varying degrees of cohesion and friction; the underground resistance (et Monsieur Coulomb’s creation) against tectonic upheaval and the “means-to-an-end” exogenic processes of internal stress. Stress and strain are in effect the micro-mechanisms within a dynamic, geological system where the processes of tectonics, metamorphism, crystallisation, lithification and weathering linger as shadowy manipulators. On a global scale the effects of strain are visible in the folding and faulting of landscapes, the pluming of fires and the pulsing of earthquakes. Returning to the fundamentals of geomorphology. Peering into the deep chasms relies upon a consciousness of the present and its dangers, essentially, as Martin Amis, in his acerbic, bachelored tones, would write: it is necessary for a continued gradualist discourse, “the future could go this way, that way. The future's futures have never looked so rocky. Don't put money on it. Take my advice and stick to the present. It's the real stuff, the only stuff, it's all there is, the present, the panting present.”

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