Pine Growth Variation Associated with Overburden Rock Type on a Reclaimed Surface Mine in Virginia

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ABSTRACT

This study was designed to compare the effects of two overburden spoil types and various mixtures of the two spoils on the performance of pitch × loblolly hybrid pine (*Pinus* × *rigitaeda*). Sandstone and siltstone overburden were used to create five rock mix treatments: pure sandstone (SS), pure siltstone (SiS), a 2:1 SS/SiS mix, a 1:1 SS/SiS mix, and a 1:2 SS/SiS mix. Tree survival was not affected by rock mix, but growth was greatly affected. The greatest growth response occurred on the SS treatment and decreased as the amount of siltstone increased in the rock mix. The average stem volume of trees on the SS treatment was nearly five times greater than trees on the SiS treatment. The coarse fragment content of the SS (52%) was much lower than the SiS (72%), thus providing a greater volume of fine earth (<2 mm) for water retention and root exploitation. The pH of the SS was much lower than SiS (5.7 vs. 7.1), and available Mn was higher in the SS than in the SiS (540 vs. 160 mg kg^{-1} foliar Mn). The results of this study demonstrate the need to consider the effects of various overburden types on tree growth when forest land is the designated post-mining land use.

FORESTRY is a logical land use for many reclaimed mined sites in the Appalachians, especially those that are too remote or steep to be useful for crops, hay production, or grazing. Studies have revealed that excellent tree growth is possible on reclaimed mined sites. Torbert et al. (1988) reported white pine (*Pinus strobus* L.) heights of up to 6.9 m for 10-yr-old white pines on reclaimed sites in Virginia. On mined sites in Illinois, Ashby et al. (1984) reported excellent growth of 30-yr-old white oak (*Quercus alba* L.) and yellow-poplar (*Liriodendron tulipifera* L.) with site indices (base age 50) of 28.6 and 29.6 m, respectively. Growth exceeded that which is normally obtained on adjacent unmined soil. In both cases, the trees were growing in deep material consisting primarily of rock fragments.

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Coal seams in the Virginia Appalachians and surrounding states are commonly overlain by sandstone and siltstone strata, over which thin, lithic soils have developed. These layers of rock are blasted and removed during the mining process and must be moved back into position during reclamation. Because natural soils are often too shallow to recover and replace during reclamation, "topsoil substitute" variances are allowed by law and are often issued to allow coal operators to place selected overburdens on the surface as a substitute or supplement for natural soils. Most state regulations require that the best available overburden material be used as the topsoil substitute. In the mid-Appalachian region, siltstone overburdens are often selected because they appear to be good media for establishing ground-cover grasses and legumes. They are usually less acidic than sandstone minesoils, and their finer texture retains surface moisture for longer periods, which enhances seedling emergence.

Little research, however, has been done to determine what effects overburden differences have on tree growth, and whether or not minesoil properties generally considered good for grasses and legumes are desirable for trees. In a greenhouse study, Preve et al. (1984) found that a sandstone spoil was a better growth medium than a siltstone spoil for *Pinus* spp. seedlings established from seed. They reported that the sandstone overburden was better because it had fewer coarse fragments, better aeration, and lower levels of soluble salts. It was still uncertain, however, how older trees would respond to these rock types under field conditions.

The purpose of this paper is to report results of a 5-yr-old controlled field study designed to compare the effects of a sandstone spoil, a siltstone spoil, and various mixtures of the two spoils on pitch × loblolly pine survival and growth on a reclaimed mined site in Wise County, Virginia.

METHODS

The study plots were constructed during the winter of 1982 on a previously mined flat bench. The study consisted of four replications of five overburden mixes that included pure sandstone (SS), pure siltstone (SiS), 2:1 SS:SiS, 1:1 SS:SiS, and 1:2 SS:SiS arranged in a randomized complete block design. The overburden was obtained from an adjacent mining operation involving the Taggart and Taggart Marker coal seams of the Marcum Hollow member of the Upper Wise Formation. Sandstone and siltstone overburden materials were stockpiled separately. Once a sufficient amount of spoil was collected, the spoils were mixed in the required ratios and placed in the center of 3.05 × 6.1 m plots. After all spoil mixtures were in place, each pile was graded flat with a small (D-4 Caterpillar) bulldozer, taking care to minimize compaction. Once grading was completed, the area was flat with a loose spoil depth of 1.25 m over a highly compacted underlying bench.

The entire study area was fertilized with 168 kg ha^{-1} N, 147 kg ha^{-1} P, and 137 kg ha^{-1} K, as NH_4NO_3, $(NH_4)_2HPO_4$, and KCl. During May 1982, All plots were mulched with straw (2700 kg ha^{-1}) and hydroseeded with a slurry containing Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.; 80 kg ha^{-1}) and wood fiber mulch (840 kg ha^{-1}). Half of each plot was used for a parallel study evaluating the effects of spoil type on tall fescue yields and nutrition (Daniels et al., 1984; Roberts et al., 1988a,b).

In April 1983, the portion of each plot used for this study was broadcast sprayed with glyphosate to kill the ground cover, and 12 containerized pitch × loblolly hybrid pine (*Pinus* × *rigitaeda*) seedlings were planted on a 0.75 m by 0.75 m spacing. Tree seed was collected from a 15-yr-old pitch × loblolly hybrid pine seed orchard at Virginia Tech's Reynold's Homestead Research center on the Virginia Piedmont. Pine seedlings were grown in a greenhouse from this seed in Spencer-Lamaire root trainers (Hillson model, 150 cc/cavity) for 16 wk prior to planting. Seedlings were planted with a 21 g slow-release fertilizer pellet (20–10–15).

After the third growing season, foliage was collected from fully-elongated current year's foliage from the top third of each tree and a composite soil sample was collected from each plot. Soil samples were taken by collecting all soil within two randomly selected 30 by 30 cm areas to a depth of 20 cm. These samples were composited and a subsample was withdrawn for analysis. Tree height and basal diameter were measured after the second, third, fourth, and fifth growing seasons.

Soil samples were sieved to separate coarse fragments from the fine-earth fraction (<2 mm). Coarse fragment content was determined by weight. Of the fine-earth fraction, percent sand was determined as the the oven-dry weight of particles trapped by a no. 270 sieve, percent clay was determined from 2-h hydrometer readings, and percent silt was calculated as the remainder. Moisture retention of the fine-earth fraction of these spoils was determined at field capacity (33 kPa) and permanent wilting point (1500 kPa) during the second growing season (1984). Moisture retention was reported as water available between 33 and 1500 kPa on a whole-soil basis by Roberts et al. (1988a). Soil pH was determined in a 1:1 soil/water mixture with a glass electrode (McLean, 1982), and soluble salts were determined by measuring the electrical conductivity of a 1:5 soil/water extract (Rhoades, 1982). Exchangeable P, K, Ca, and Mg were extracted with 1 *M* NH_4OAc and determined by colorometric spectrophometry (P), atmoic adsorption spectrophotometry (Ca and Mg), and flame emission (K).

Needle tissue was dried to a constant weight at 65 °C and ground in a Wiley mill to pass a 1-mm screen. Foliar N was determined colormetrically after Kjeldahl digestion by the method of Bremner and Mulvaney (1982). To determine foliar P, K, Ca, Mg, Fe, Zn, Mn, and Na concentrations, samples were dry ashed at 450 °C, extracted with 6 *M* HCl, and analyzed with an inductively coupled plasma emission spectrophotometer.

RESULTS AND DISCUSSION

Tree Performance as Affected by Rock Type

After 5 yr, overall survival was 91% and not significantly affected by rock type. There was a highly significant ($P \geq 0.0001$) relationship between the proportion of sandstone in the rock mixture and tree volume (Fig. 1). Trees in the SS treatment plots had the highest average height and diameter; 1.91 m and 4.6 cm, respectively. Height and diameter in the SiS treatment averaged 1.12 m and 2.5 cm. The average tree volume in SS plots was almost five times greater than the volume of trees in the SiS plots (1858 cm^3 vs. 382 cm^3) and was nearly as high as that of trees of the same species growing on undisturbed soils in Patrick County, VA (R.E. Kreh, 1988, personal communication).

A linear transformation of the data (based on the natural logarithm of the square root of volume) revealed significant differences in growth rates among the SS, 1:1 mixture, and SiS plots. Diverging growth patterns between these rock mixtures (Fig. 2) indicate that these differences will continue with time.

Growth-Limiting Mine Spoil Physical and Chemical Properties

Coarse fragment content and texture varied along the SS to SiS gradient. Coarse fragment content was

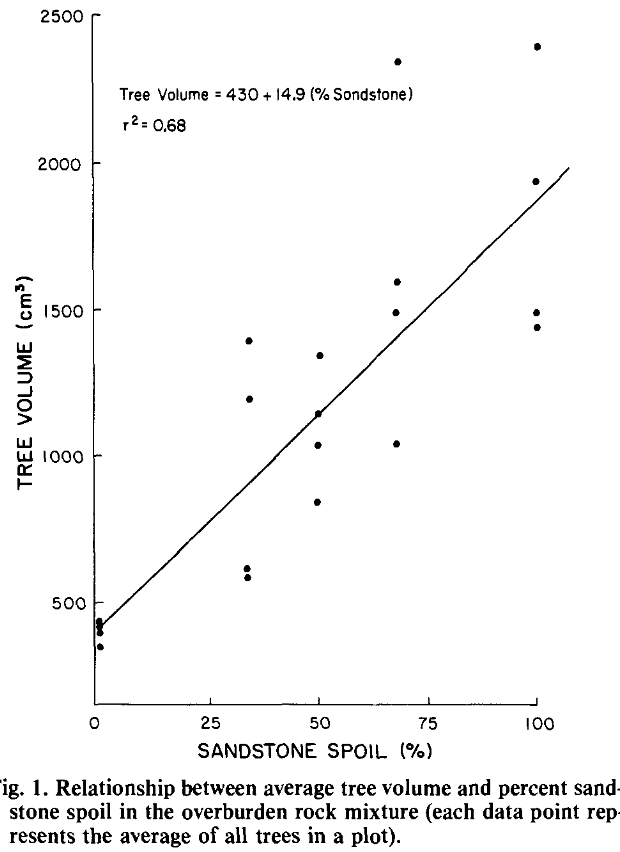

Fig. 1. Relationship between average tree volume and percent sandstone spoil in the overburden rock mixture (each data point represents the average of all trees in a plot).

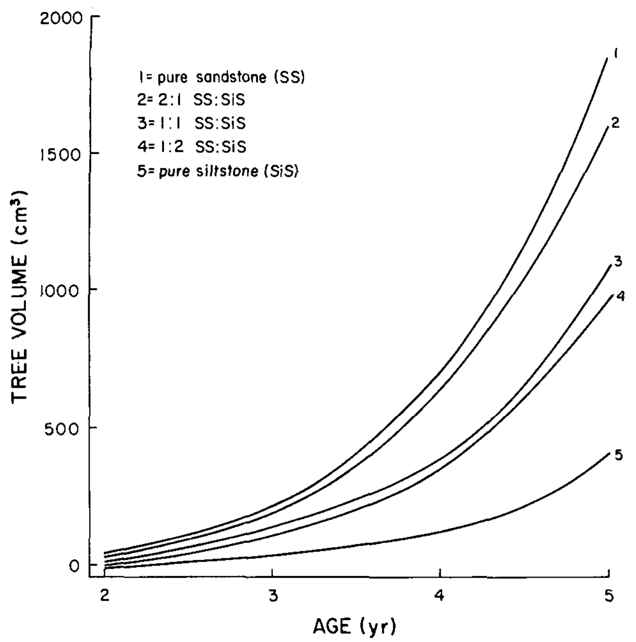

Fig. 2. Average tree volume for each overburden rock mixture through age five.

high in all rock mixes, but was highest in the SiS plots (74% for SiS vs. 52% for SS) (Table 1). The percent sand in the fine-earth fraction ranged from 57% in the SiS plots to 74% in the SS plots. Silt increased from 15% in the SS to 29% in the SiS plots. The clay fraction was unaffected by treatment and averaged about 12%. Despite the differences in sand and silt concentrations, the fine-earth texture for all spoil treatments fell within the USDA sandy loam textural class. The whole-soil texture was extremely gravelly sandy loam.

Despite similar textures of the fine-earth fraction, whole-soil available water holding capacity was diminished significantly by increasing contents of SiS spoil due to the higher coarse fragment content of this rock type. Water holding capacity of the SiS spoil was 24 g kg^{-1} vs. 43 g kg^{-1}, or about one-half that of the SS spoil. Continuous soil moisture monitoring for 5 yr in this remote area was not practical; however, area precipitation data (NOAA, 1987) for the 5-yr study period showed that the summers of 1983, 1984, and 1987 were below normal, and that numerous times during the five growing seasons precipitation was less than 50% of normal (Fig. 3).

It has been well established that a soil moisture deficit during the growing season is the single-most important edaphic factor limiting the growth of the region's forests. The USDA soil surveys show that slight differences in exploitable soil volumes cause concomitant differences in site indicies of all measured tree species. In these study plots, given the available water holding capacities of the useable minesoil volume, widely fluctuating precipitation levels, and water demand of these trees, even the SS plots would have reached deficit levels several times each growing season. Therefore, maximizing exploitable soil volume via deliberate overburden selection is clearly necessary for optimizing wood production.

The sandstone spoil had a significantly lower pH,

Table 1. Physical properties of spoil mixtures used in this study.

Treatment	Whole-soil coarse fragment content	Fine-earth particle size distribution: Sand	Silt	Clay	Whole-soil water retention† (1500–33 kPa)
	%				g kg^{-1}
Sandstone (SS)	52b*	74a	15d	12a	43a
2:1 SS/SiS	57ab	71ab	18c	11a	45a
1:1 SS/SiS	64ab	68bc	20b	12a	39a
1:2 SS/SiS	63a	64c	23ab	13a	37ab
Siltstone (SiS)	74a	57d	29a	13a	24b

* Mean values within a column followed by the same letters are not different ($P \leq 0.05$).
† From Roberts et al., 1988a.

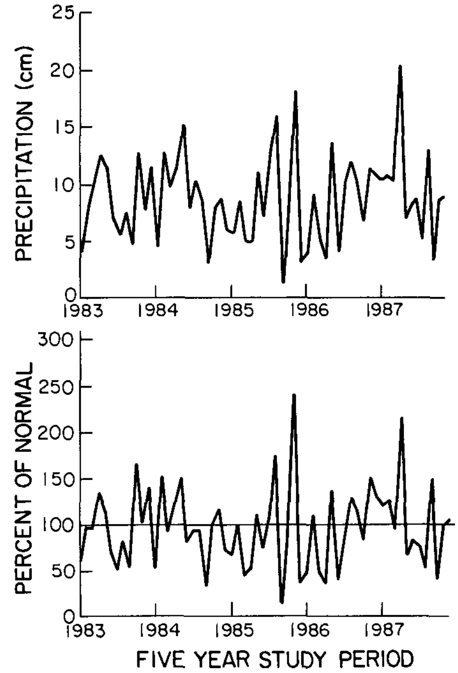

Fig. 3. Plots of mean monthly precipitation and percent of normal (1951–1980) precipitation during the 5-yr study period for the area surrounding the study site (NOAA, 1987).

lower level of soluble salts, and lower levels of exchangeable K, Ca, and Mg than the siltstone spoil. Levels of exchangeable P did not vary among rock mixes, but the sandstone in this study had a higher level of plant-available Mn than the siltstone spoil (Daniels et al., 1984) (Table 2).

There was a distinct inverse relationship between tree volume and mine soil pH (Fig. 4) that was stronger ($r^2 = 0.86$) than any other volume/minesoil relationship. Compared with agronomic crops, conifers are better adapted and are more productive on somewhat acidic soils (Pritchett, 1979). Part of this adaptation has to do with their symbiotic association with mycorrhizal fungi, which play an important role in the rhizosphere of conifers (Marx, 1977). Most ectomycorrhizae associated with conifers do not thrive when the soil pH exceeds 6.5 (Theodorow and Bowen, 1969). Schoenholtz et al. (1987) compared mycorrhizal colonization rates for three pine species growing in two different minesoils with pH values of 5.4 and 6.1, respectively. Numbers of trees and numbers of short roots per tree colonized were consistently higher at the

Table 2. Chemical properties of spoil mixtures used in this study.

Treatment	pH	Soluble salts	NH₄OAc exchangeable nutrient				Plant-available Mn†
			P	K	Ca	Mg	
		dS m⁻¹	mg kg⁻¹				
Sandstone	5.7c*	0.4d	47a	49c	435d	162b	216‡
2:1 SS/SiS	6.2b	0.7c	56a	62b	548c	206a	194
1:1 SS/SiS	6.4b	0.7c	53a	60b	562c	215a	185
1:2 SS/SiS	6.6b	0.9b	51a	63b	666b	220a	164
Siltstone	7.1a	1.3a	42a	73a	777a	227a	115

* Mean values within a column followed by the same letters are not different ($P \leq 0.05$).
† Plant-available Mn = NH_4OAc exchangeable Mn + easily reducible Mn (Daniels et al., 1984).
‡ From Daniels et al. (1984); statistical differences between treatments not published.

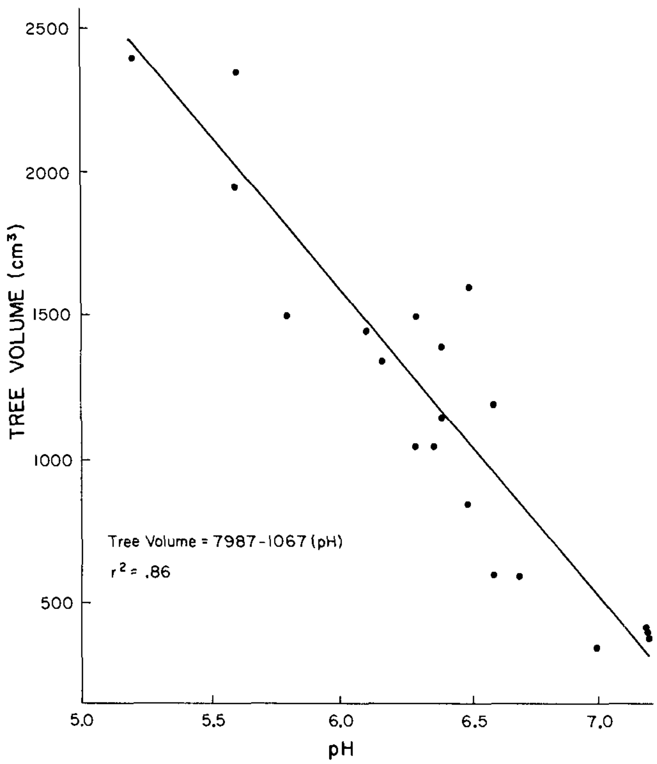

Fig. 4. Relationship between average tree volume and mine soil pH (each data point represents the average of all trees in a plot).

lower pH. The colonized trees survived and grew better.

Nutrient availability can also be affected by pH within the range of values encountered in this study (5.7 -7.1); however, except for Mn, foliar levels were not greatly different among treatments (Table 3). Magnesium was slightly higher in trees in SiS plots and lowest in trees in the SS plots (1.6 g kg⁻¹ vs. 1.2 g kg⁻¹). Foliar N, P, K, and Ca levels were not affected by treatment, and, along with Mg, exceeded the critical levels of 12.0 g kg⁻¹ N, 1.0 g kg⁻¹ P, 3.5 g kg⁻¹ K, 1.2 g kg⁻¹ Ca, and 0.7 g kg⁻¹ Mg, which are generally accepted for loblolly pine (*Pinus taeda* L.; Allen, 1987; Fowells and Krauss, 1959; Wells and Crutchfield, 1973; Stone, 1968) Foliar Fe, Zn, and Na were also unaffected by treatment. The average foliar Mn concentration of trees in SS plots (540 mg kg⁻¹) was 240% higher than the average concentration in SiS plots (160 mg kg⁻¹), and there was a very significant ($P \geq 0.0001$) relationship between foliar Mn concentration and tree volume (Fig. 5).

Table 3. Nitrogen, P, K, Ca, and Mg concentrations in hybrid pine foliage as affected by rock mixtures.

Treatment	Foliar nutrients: N	P	K	Ca	Mg	Mn
	g kg⁻¹					mg kg⁻¹
Sandstone (SS)	15.6	1.3	4.4	2.3	1.2b*	540a
2:1 SS/SiS	15.9	1.3	4.8	2.3	1.3b	300b
1:1 SS/SiS	16.3	1.3	4.7	2.3	1.3ab	270bc
1:2 SS/SiS	16.6	1.4	4.7	2.4	1.4ab	210bc
Siltstone (SiS)	16.4	1.4	4.6	2.6	1.6a	160c

* Mean values within a column followed by the same letters are not different ($P \leq 0.05$).

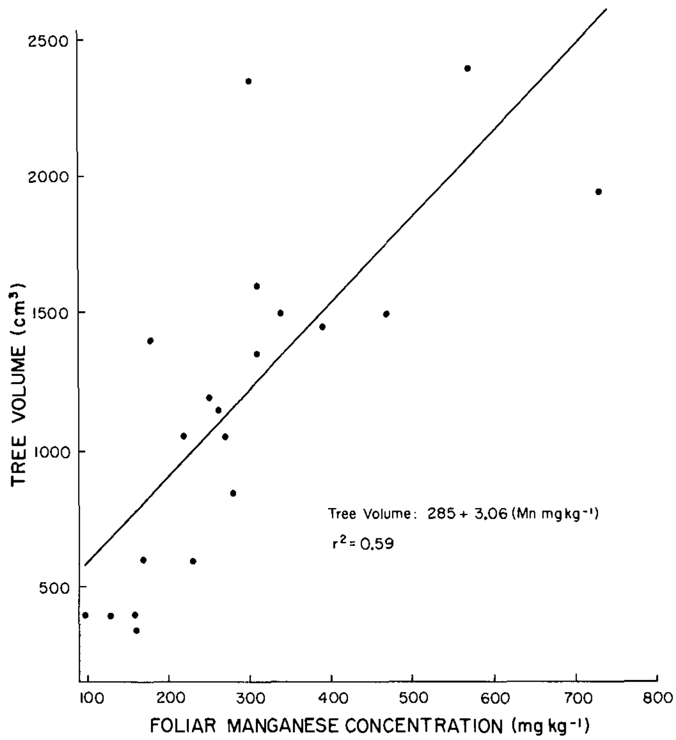

Fig. 5. Relationship between average tree volume and foliar Mn concentration (each data point represents the average of all trees in a plot).

Manganese availability decreases as soil pH increases (Marschner 1986); this relationship was clearly observed in this study (Table 2). Manganese deficiencies are infrequent in conifers growing in undisturbed acidic soils; therefore, sufficiency levels are not well documented. In a review of micronutrients in forest trees, Stone (1968) listed Mn levels of 300 to 400 mg kg⁻¹ as intermediate in range for loblolly pine. Moss et al. (1989) reported very poor pine growth as a result of Mn deficiency where a high pH and high organic matter content in sewage sludge–amended mine soils resulted in foliar Mn levels of less than 100 mg kg⁻¹. Values in this study ranged from 160 to 540 mg kg⁻¹, exceeding both ends of the intermediate range. The highest levels of foliar Mn in the SS plots may represent luxury consumption, whereas the lowest levels in SiS plots appear to be below normal based on Stone's (1968) review.

CONCLUSION

Objectives of surface mine reclamation include stabilization of the mined land, prevention of erosion and water pollution, and construction of a site that is suitable and productive for the intended post-mining land use. Unfortunately, the nature of overburden materials that will maximize tree growth and wood production is poorly understood or overlooked. Even when the designated post mining land use is forest land, minespoils are often selected for grasses and legumes that serve only as temporary cover crops. Siltsones and shales are frequently placed at the surface to enhance herbaceous seed germination at the expense of long-term forest productivity.

This study shows that physical and chemical properties are very different among overburden types available for surface application, and that these properties directly or indirectly affect the productivity of the minesoils that develop. Sandstone-derived minesoils produced five times more stem volume than siltstone-derived minesoils. On this mid-Appalachian site, water holding capacity as affected by coarse fragment content was nearly twice as high in the sandstone-derived minesoils than in the siltstone-derived minesoil. The most important chemical properties associated with tree growth were pH and available Mn as shown by highly significant relationships with tree volume. The study demonstrated that near-neutral siltstone spoils, commonly selected as topsoil substitutes in this region, are very detrimental to tree growth, whereas minesoils developing from moderately acid sandstone spoils can be nearly as productive as undisturbed forest sites.

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