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PETROGRAPHIC STUDY OF DEVONIAN SHALES AND SILTSTONES AT ROAD-CUT ON ROUTE 33 EAST OF ELKINS, WV

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INTRODUCTION

This petrographic study is based on samples collected by J. Schwietering from the lower part of the Devonian section exposed on the new road-cut on Route 33 east of Elkins. J. Schwietering described the rocks in detail megascopically. The rocks are mainly shales and siltstones with a few very fine sandstones and some limey layers. The specimen numbers used in this study refer to the number of feet above the base of this measured section.

MINERALOGY

Quartz occurs in monocrystalline grains, fine-grained metaquartzite, and as a constituent of the schist grains. Some of the grains of cryptocrystalline quartz may represent chert or very fine-grained quartzite.

Feldspar was present in most specimens with some sandstones containing as much as 13% feldspar. The original content was even higher because appreciable amounts were completely replaced by quartz. The feldspar is exclusively plagioclase in the form of oligoclase. Although potash feldspar usually occurs with plagioclase, several methods of identification indicated that the feldspar was solely plagioclase. In thin section, no twinning typical of microcline or diagnostic perthite was observed. Index of refraction determined by the immersion method revealed only plagioclase. Staining confirmed the presence of plagioclase but no potash feldspar. X-ray analysis showed plagioclase in every specimen without any potash feldspar.

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Mineral Composition from Thin Section (%)

Feet from base of Section	Quartz & Feldspar	Phyllo-silicate	Course Mica Flakes	Organic Matter	Carbonate	Miscl.
5	22	73		1	0.3	4
141.5	40	56	1.7	1	tr	1
213	29	65	2.0		1.0	3
406	24	71			0.3	4
598	43	52	0.3	1		3
656	43	52	0.7	1	0.7	3
700	62	4		6	25.5	2
816.5	52	34	0.3	1	10.0	2
931	86[1]	6	0.7	7	0.3	
1225	43	46		8	0.7	2
1455	64	18	0.7	4	9.0	4
1517	76	7		1	12.7	3
1604	57	19	1.0	16	2.0	5

[1]Includes 13% feldspar (stained section)

The most common phyllosilicates were fine-grained muscovite or illite. Kaolinite was not easily recognized in thin section but X-ray indicated only a few specimens contained appreciable kaolinite. Coarse flakes of muscovite and biotite were noticeable in most specimens. Much of the biotite was fresh but some was partially bleached indicating loss of some of the potassium. Chlorite occurred in minor amounts and appeared to be detrital rather than in situ alteration of biotite.

About half of the specimens studied in thin section contained a percent or more of carbonate. In the most calcareous specimens, much of the calcite occurred in fossil shells. The specimen at 1176' is actually a fossiliferous limestone with only small amounts of quartz. Where calcite constituted 10% or less of the specimen, it was usually secondary and tended to replace argillaceous material and feldspar. Small amounts of carbonate weathered brown indicating ankerite or siderite.

It is of particular interest to note that small amounts of sphalerite were observed in the thin section of the sandstone at 1604'. The sphalerite was mainly of replacement origin and particularly attacked phyllosilicates. Replacement of biotite could have furnished iron for the sphalerite. In hand specimen of this sandstone, reddish brown euhedral sphalerite could be seen along fractures. This material resembles ruby zinc which is a variety of low iron sphalerite. Smaller amounts of galena in the form of cubes occur with the sphalerite.

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COMPARISON OF THIN SECTION DETERMINATIONS

WITH X-RAY AND ELEMENTAL ANALYSES.

X-ray diffraction and elemental analyses were run by J. Renton on the same specimens that were thin sectioned. The trends in mineral variation determined in thin section correspond fairly well with those determined by X-ray diffraction (fig. 1 and 2). Quartz plus feldspar determined in thin section corresponds well with the X-ray analysis in the quartzose rocks. In the highly argillaceous rocks the quartz runs lower apparently because some of the fine quartz could not be observed in thin section. Some of the scatter in the plotted points was probably due to the fact that the thin section was not exactly representative of the specimen analyzed.

In comparing the phyllosilicate determinations by X-ray and thin section there is considerable scatter in the plotted points (fig. 2). Because of the heterogeneity of some of these rocks, it is possible that the specimen sampled for thin section differed from the X-rayed sample.

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The trends in mineral variation agreed with the main trends determined by elemental analysis. As shown in figures 3 and 4 , the increase in quartz content (including minor feldspar in thin section)corresponds quite well with the silica content determined by elemental analysis. The straight line running through the average position of the points in each of these graphs cuts the abscissa close to 50% SiO_2. Theoretically this represents the silica content of the components other than quartz in these rocks. This checks out well because the chief component besides quartz is illite which typically has content of about 50% SiO_2.

In most specimens the carbonate content determined in thin section agrees with the geochemical data in terms of CaO content. As seen in figure 5 the specimens with more carbonate are richer in dolomite than calcite as the points fall closer to the theoretical curve for pure dolomite. The point for specimen

Quartz plus feldspar by x-ray
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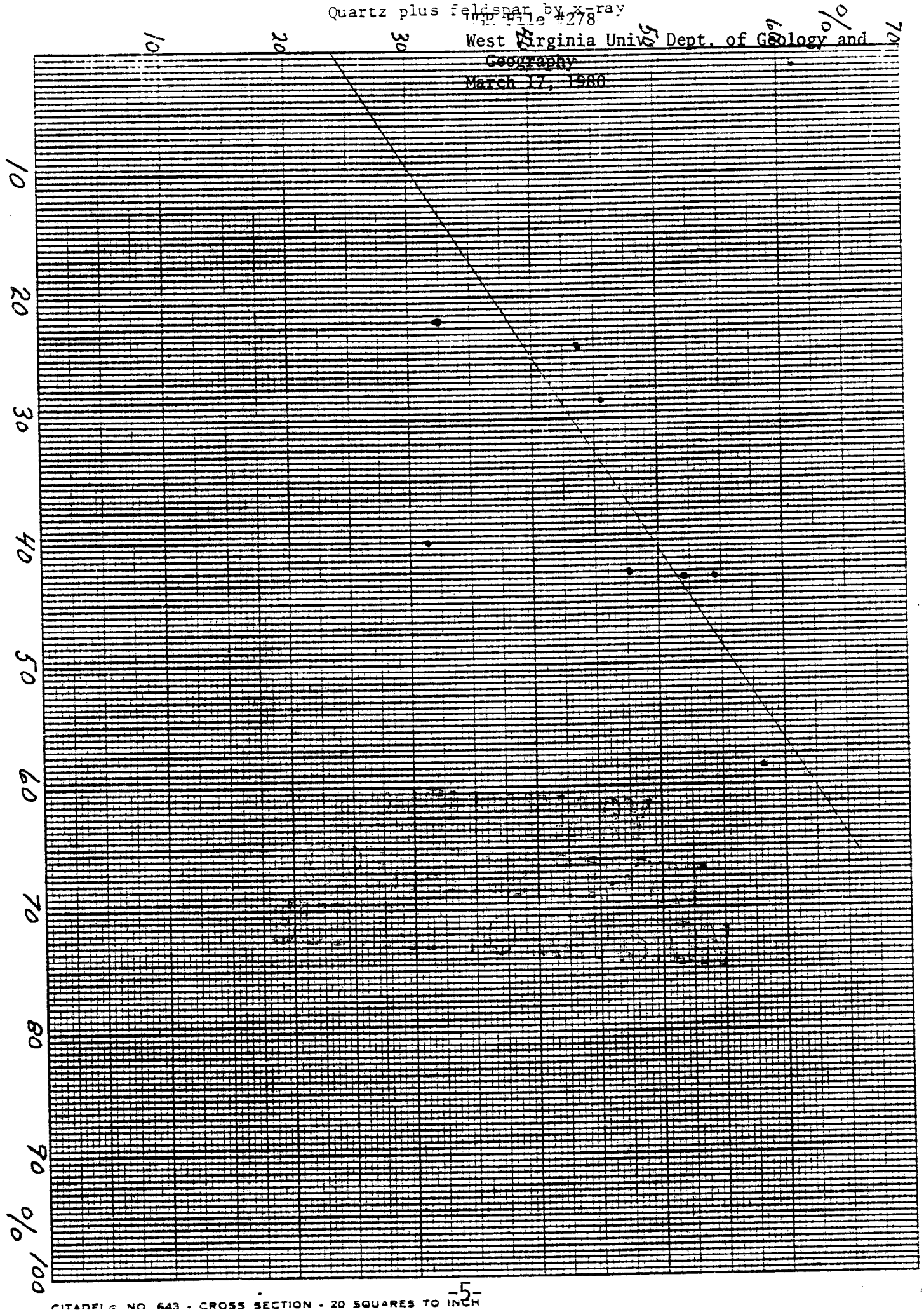

Fig. 1 Quartz plus feldspar in thin section

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Phyllosilicates by x-ray
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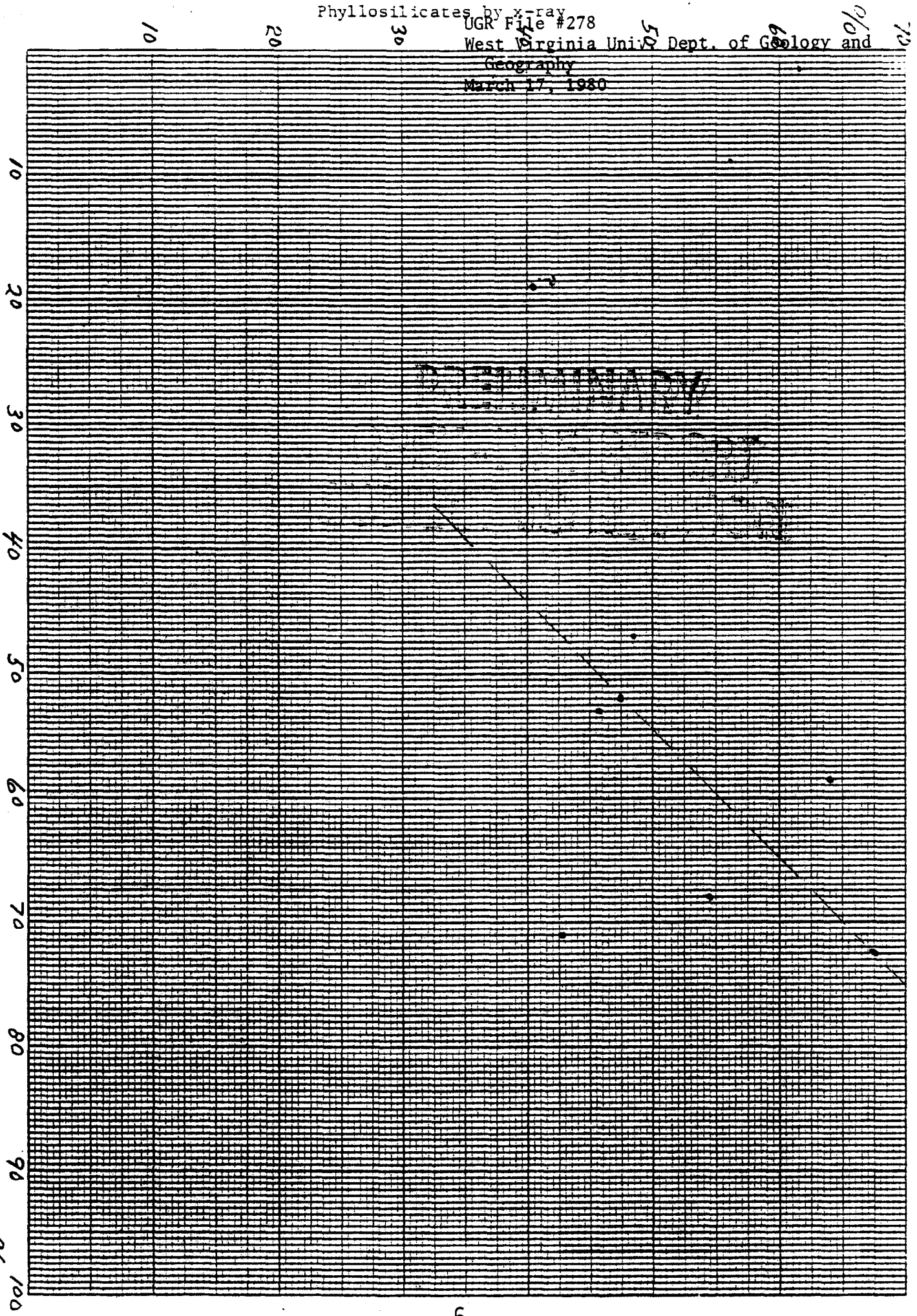

Fig. 2 Phyllosilicates in thin section

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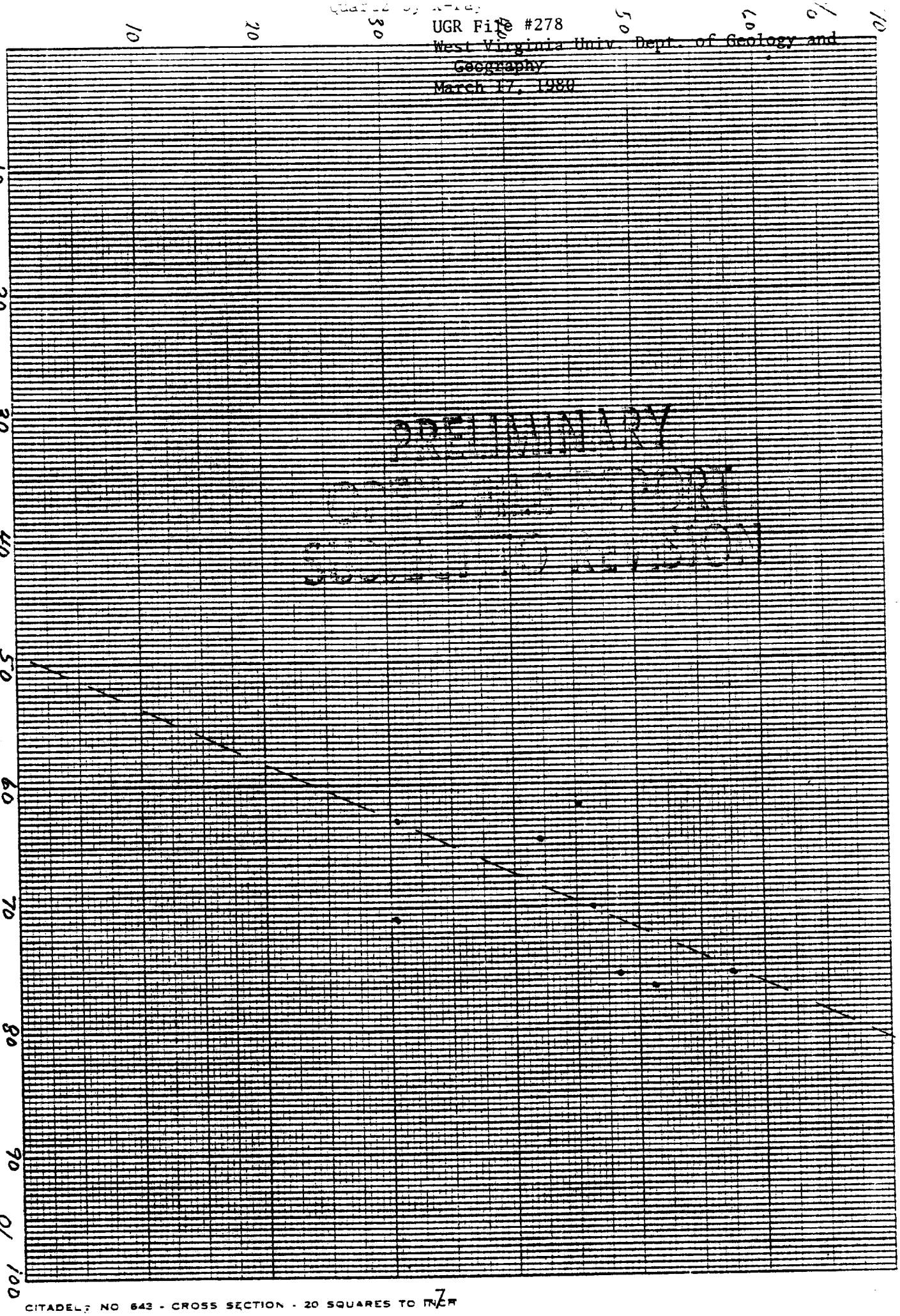

Fig. 3 SiO_2 by elemental analysis

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Quartz + minor feld in thin section

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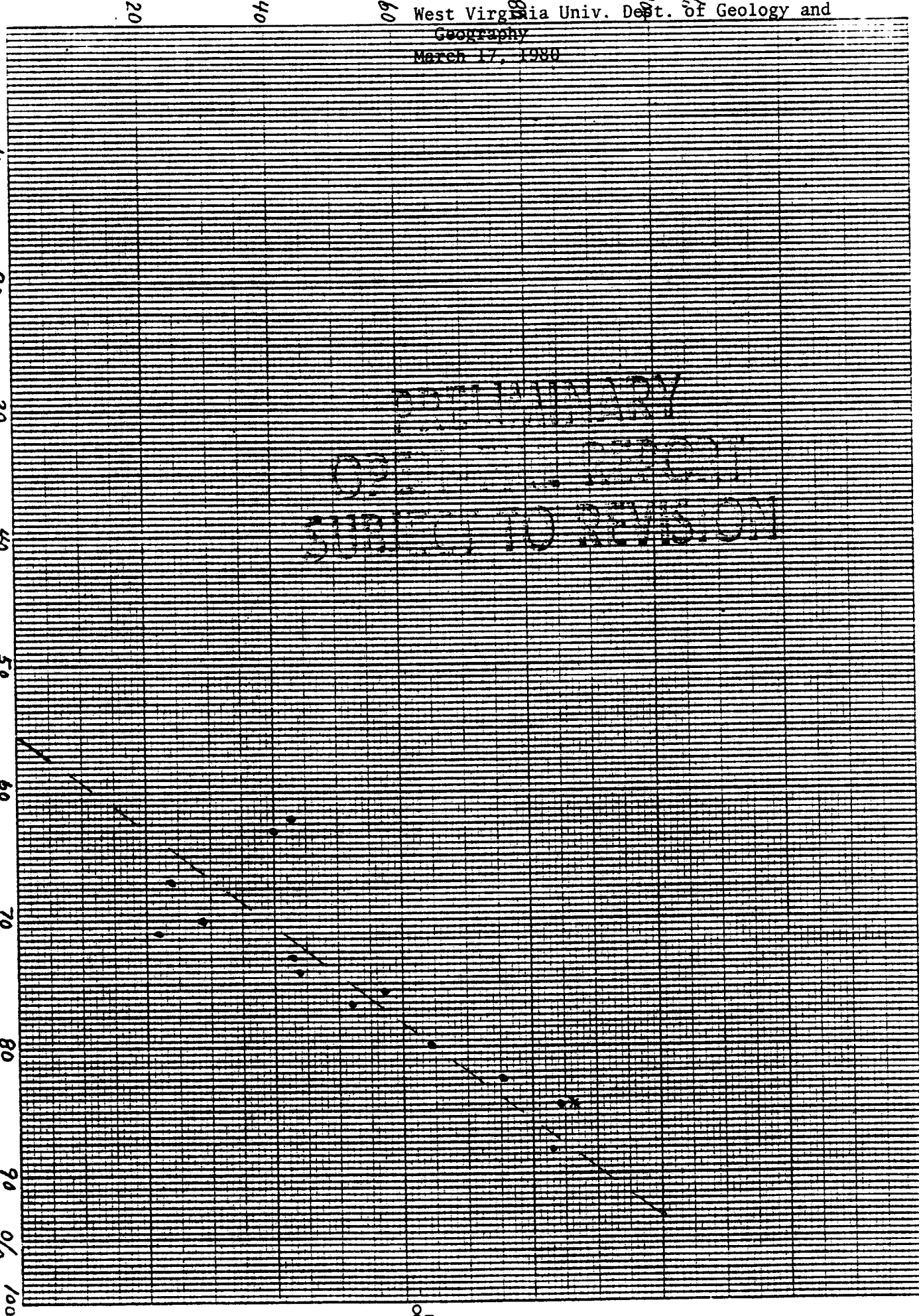

Fig. 4

*Calcareous specimen recalculated to 100% after subtracting carbonate and CaO

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Carbonate in thin section

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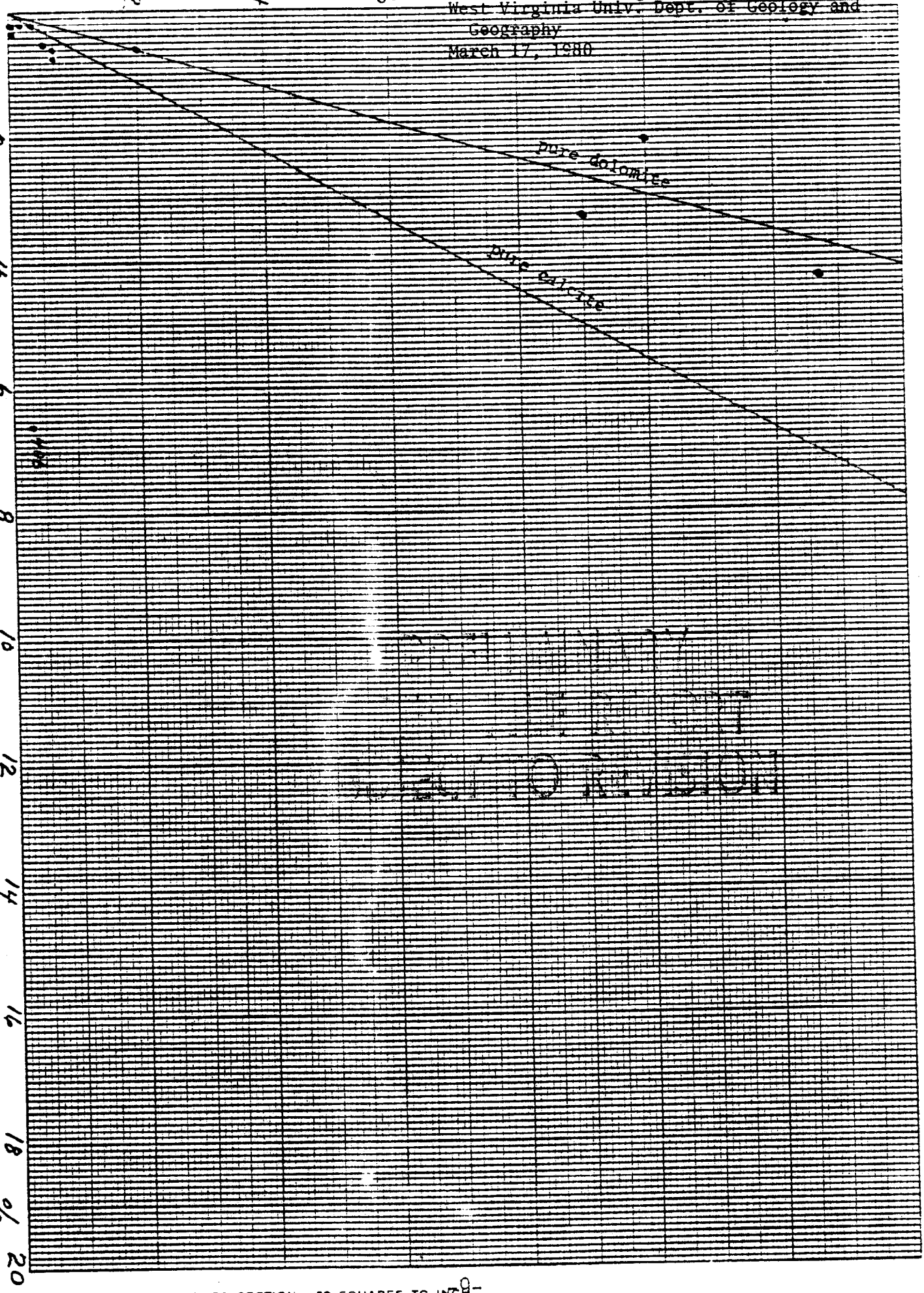

Fig.5

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406 falls far from the curves. Either there was a difference in lithology between the specimen thin sectioned and the analyzed specimen or there was an analytical error.

These specimens contain various phyllosilicates -- illite, muscovite, biotite, chlorite, kaolinite and possibly other clay minerals. Because of variations in the proportions of these phyllosilicates as well as feldspar, there is some scatter when the percentages of phyllosilicates are plotted against Al_2O_3 but the general trend is consistent (fig. 6). Moderate amounts of biotite and minor chlorite are seen in thin section. This is consistent with the plot in figure 7 showing increasing phyllosilicate content with increasing iron oxide. Other iron-bearing minerals apparently are not significant. The ratio of iron oxide to alumina in the moderately argillaceous specimens indicates that illite and muscovite are about twice as abundant as biotite and chlorite.

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As shown in figure 8 , several of the oxides increase with Al_2O_3 as would be expected. The increase in K_2O with Al_2O_3 reflects the high proportion of mica and illite in the phyllosilicates. The Na_2O content is a little higher than would be expected from the mica and may reflect the presence of feldspar. As stated previously, the increase in iron oxide with Al_2O_3 is related to the occurrence of biotite. Although biotite contains Ti, the amount of Ti in these rocks is higher than would be expected for the biotite content. Some of the Ti may be in heavies such as ilmenite, sphene, and rutile. MgO is not plotted because it varies both with content of dolomite and biotite. Overall the MgO content is relatively low indicating that the biotite is somewhat lower in MgO than the average biotite.

The mineralogy of the siltstones and silty-shales gives some indication of the source rock. Grains of metamorphic rock are common. In addition to fine-grained quartzite, there are rock particles of fine grained schist. Biotite is is present so at least some metamorphic source was of middle grade intensity or

Phyllosilicate in thin section
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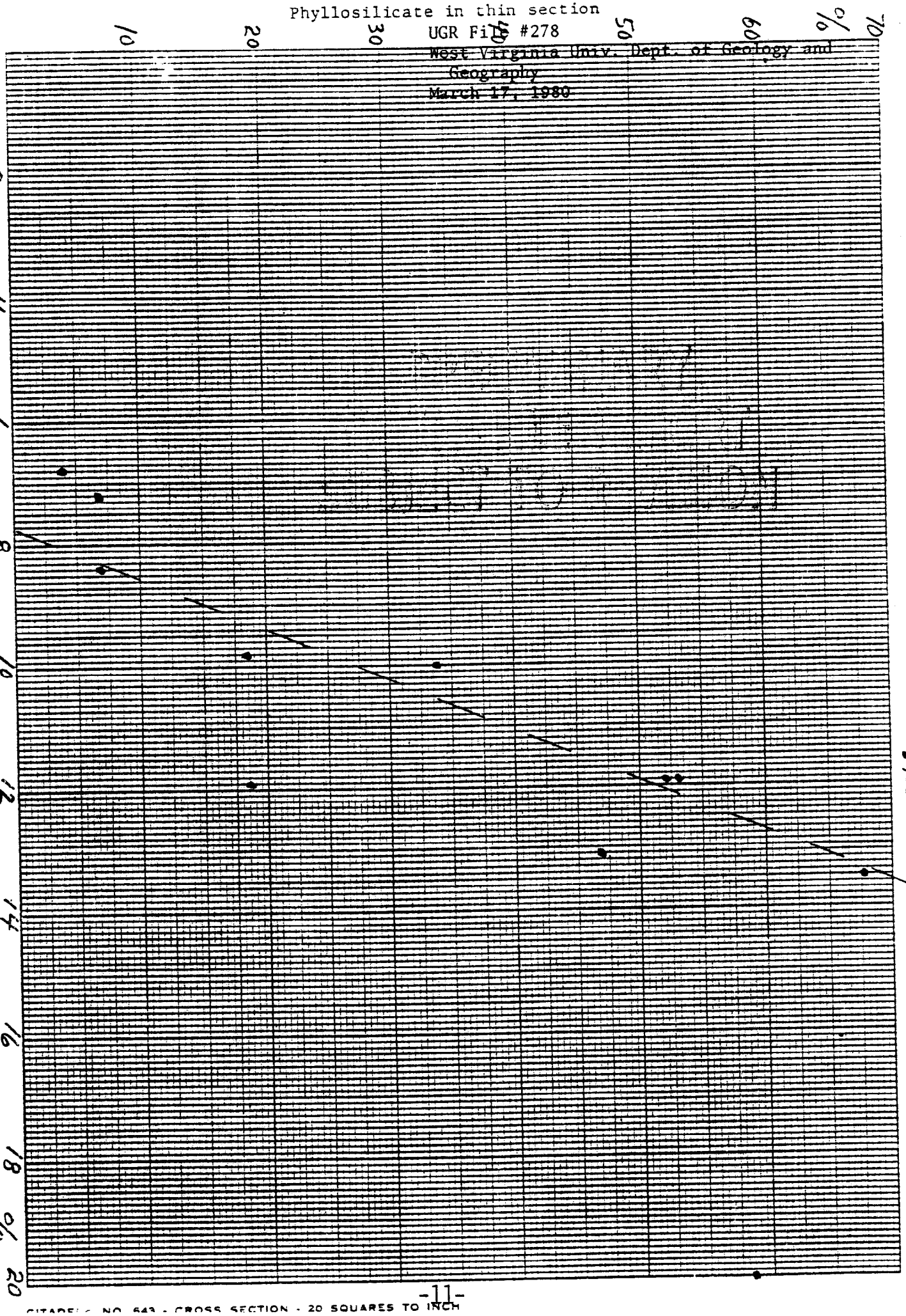

Fig. 6

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Phyllosilicated in thin section

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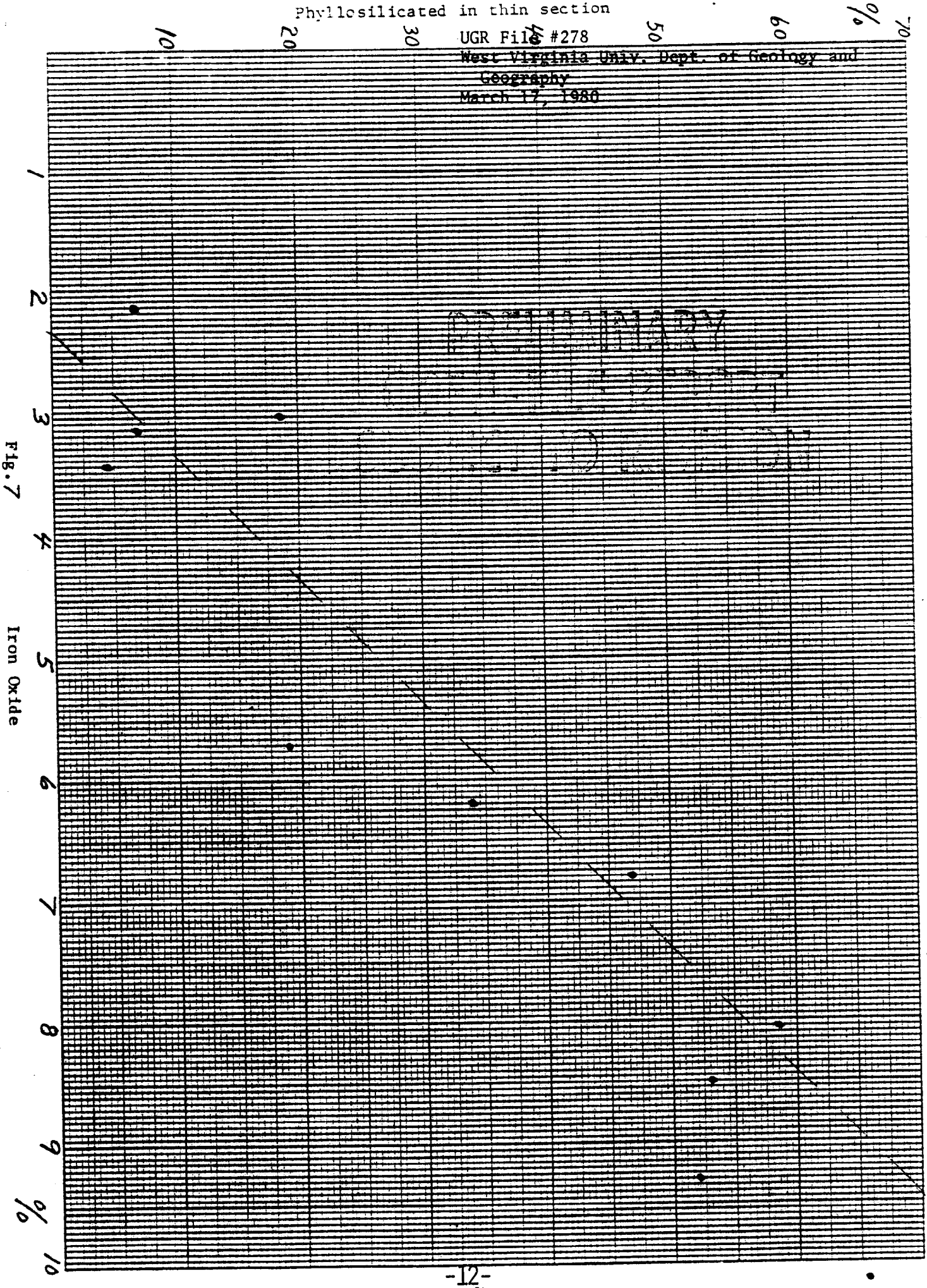

Fig. 7

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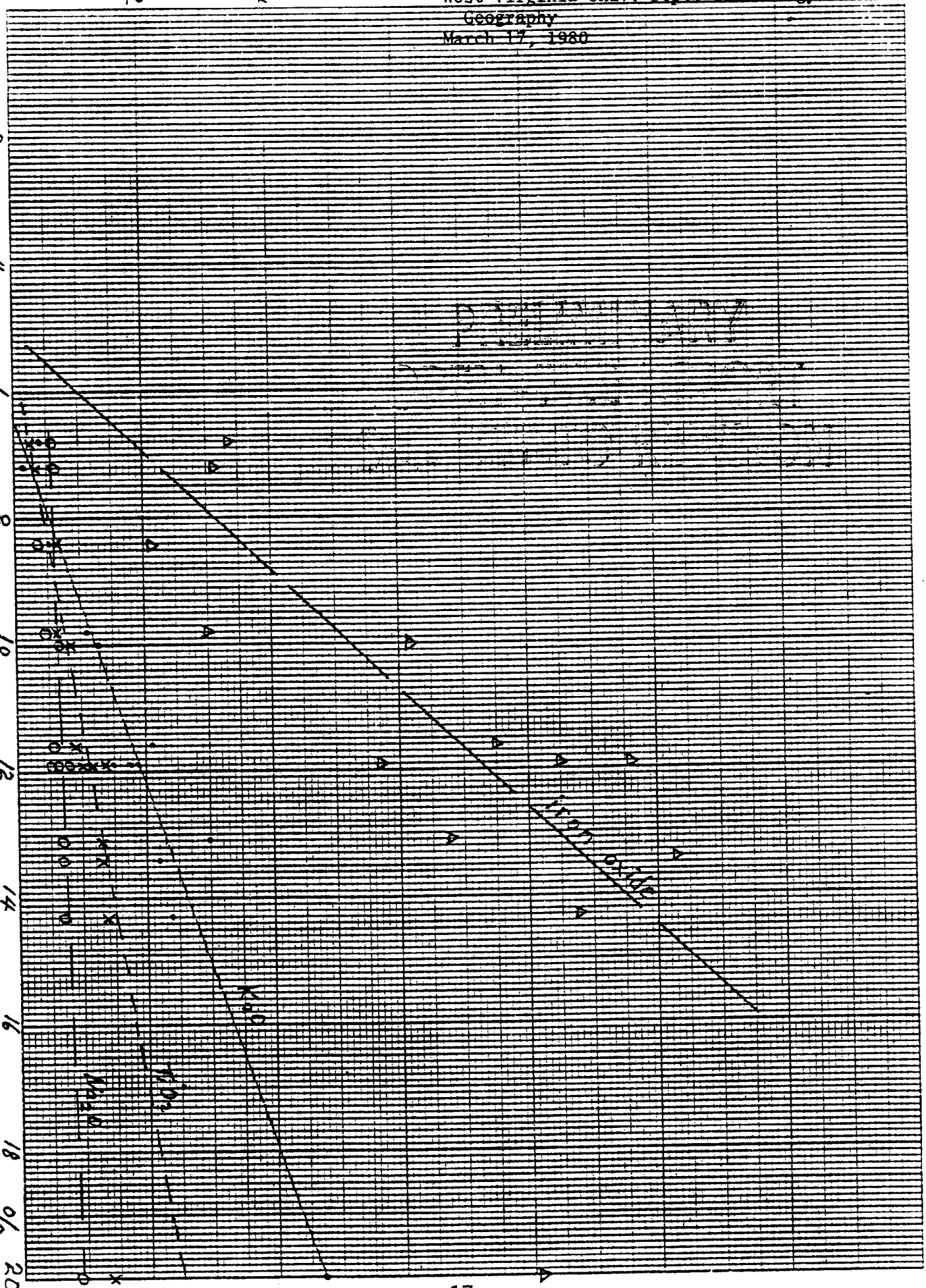

Fig. 8

CITADEL NO. 643 - CROSS SECTION - 20 SQUARES TO INCH

or higher. Feldspar content in the siltstones is significant, commonly 5-13%, yet it is exclusively oligoclase. Oliglase rather that albite also indicates metamorphism of at least middle grade. The absence of potash feldspar is noteworthy. Inasmuch as potash feldspar is normally more resistant to weathering than plagioclase, its absence from the sediments indicates it was not present in the original rocks of the source area. Apparently the source area was devoid of granite and pegmatite which are rich in potash feldspar. This is unusual as areas of schist are commonly intruded by granites and pegmatites especially in high grade zones. If the source were lower middle grade, this would explain the absence of garnet although garnet may not have survived weathering and intra-stratal solution.

The feldspars are remarkably fresh except for some diagenetic solution. Although some biotite is altered, much of it is fresh. Apparently the source area was not highly weathered and was subjected to mechanical breakdown. Therefore it may be that much of the fine material in the shales is a product of mechanical shredding of mica rather than a secondary product resulting from chemical weathering. Although all the siltstones and sandstones have phyllosilicates, much of the material represents mica in schist grains rather than fine argillaceous material.

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DIAGENESIS

Pressure solution effects are difficult to observe in fine grained rocks but at least moderate pressure solution of quartz occurred in the siltstones and sandstones. Secondary quartz was noticeable except in the quartz-poor shales. The largest amount of secondary quartz occurred in the sandstone at 931' apparently because this was a particularly clean sandstone and little clay or carbonate was present to inhibit quartz growth. Uneven growths in other specimens indicated that clay coatings interfered with quartz enlargement.

Feldspar has undergone very little alteration to clay but dissolution effects are conspicuous. The solution occurred in the subsurface rather than at the outcrop inasmuch as many of the leached voids are filled with fossil hydrocarbon. The feldspar voids are similar to those observed in the cores of the Benson sandstone. The feldspar has been partially replaced by carbonate and quartz. The quartz replacement occurred after partial dissolution of the feldspar as quartz has engulfed dissolution voids in the feldspar that are filled with hydrocarbon.

Small amounts of secondary carbonate in the form of calcite or ankerite are present in most specimens. This carbonate occurs mainly as replacement of argillaceous material and to a smaller extent feldspar.

The specimens are surprisingly fresh with only minor weathering effects. Alteration was limited to a few specimens where the small amount of iron-bearing carbonate was leached leaving voids lined with iron oxide.

ORGANIC MATERIAL

Dark brown organic material that appears to be fossil hydrocarbon fills voids in several of the fine sandstones and siltstones. The sandstone at 1604' was the richest in this fossil hydrocarbon. Measurement in thin section is not entirely accurate because of the difficulty of distinguishing between stained argillaceous material and actual hydrocarbon. However, it appears that the fossil hydrocarbon content of this sandstone is close to 15%. Only minor amounts of organic material

were indicated in this specimen by low temperature ashing apparently because most of the organic material was not of the type that is destroyed by this treatment. A thermogram of the specimen indicated considerable hydrocarbon.

The distribution of the hydrocarbon in this sandstone is very uneven with some interstices filled with hydrocarbon and others occupied by quartz free of any organic matter. There are several possible explanations for this distribution. The hydrocarbon may have entered the sandstone fairly early and because of the hydrodynamics of the system may have by-passed some patches of the sandstone and been concentrated in other patches. Quartz growth would have been blocked in the interstices filled with hydrocarbon whereas secondary quartz growth and pressure solution could have occurred in the clean interstices. In pores containing both hydrocarbon and water, quartz growth and compaction attending pressure solution could have displaced hydrocarbon leaving organic free patches. Openings developed along fractures in the sandstone after hydrocarbon entered and these openings were filled with clean secondary quartz. Thus several factors appeared to account for the irregular distribution of the hydrocarbon.

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In the sandstone at 1604' the hydrocarbon entered farily early. Secondary quartz is poorly developed in pores containing hydrocarbon apparently because waters containing silica could not enter these pores or the hydrocarbon tended to physically block the outward growth of quartz. Where secondary quartz is next to hydrocarbon it is irregular as if its growth was impeded by the hydrocarbon. However, hydrocarbon did not enter until after some dissolution of feldspar had occurred since leached voids in the feldspar are filled with hydrocarbon. The diagenetic sequence in this sandstone was:

1. Minor secondary quartz growth and pressure solution
2. Partial dissolution of feldspar
3. Entry of hydrocarbon with irregular distribution in the sandstone
4. Major quartz growth and pressure solution in areas of low hydrocarbon content.

5. Fracturing

6. Quartz filling of fractures mainly as overgrowths on grains at walls of the fractures

In the sandstone at 931' most of the secondary quartz formed before the entry of hydrocarbon. Pores are mainly filled with quartz cement and any residual interstitial pores are filled with hydrocarbon. Some secondary quartz formed after the influx of hydrocarbon. This is indicated by the fact that quartz replaced feldspar which previously had voids filled with hydrocarbon. Where replacement occurred, the hydrocarbon filled pores are left as islands in the replacing quartz.

GAMMA RADIATION

Gamma radiation as measured by J. Schwietering at the outcrop is plotted in figure 9 against phyllosilicates and organic material which are the constituents that normally account for most of the radiation. Most of the specimens without organic material fall fairly close to the straight line shown in the figure. Major deviations are probably cases in which the thin section is not representative of the area from which radiation was emanating. The points for organic-rich specimens also fall close to this line if the radiation from the organic material is calculated as 3.2 times that from phyllosilicates. It is interesting to note that some of the "hot streaks" in the Benson sand which are believed due to the presence of organic matter also yield radiation which is about 3 times stronger than that from phyllosilicates (Cheema, 1977).

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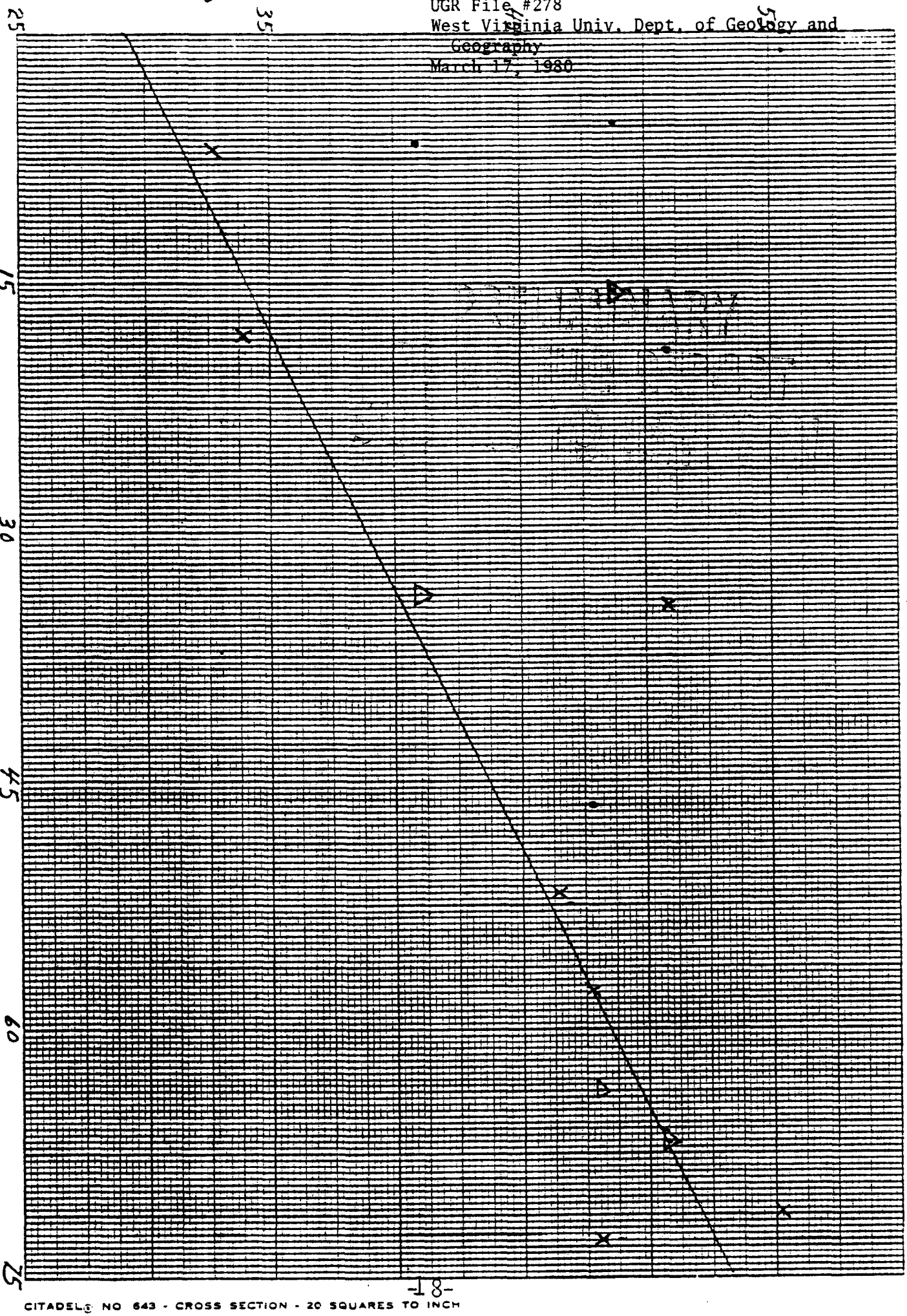

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Fig. 9

• plotted with phyllosilicates only
△ specimens with organic matter
△ same specimens plotted with phyllosilicates plus 3.2x organic matter.

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FRACTURES

Small fractures are difficult to detect in these rocks unless there is a filling of a light colored mineral. A few specimens have an occasional calcite vein as is the case at 931'. However, the sandstone at 1604' is unusual in that it is laced with small fractures. These fractures tend to be either parallel to bedding or perpendicular to bedding. The fractures observed in hand specimen are open and lined with euhedral crystals of quartz, sphalerite, and galena. In thin section, the fractures are very difficult to detect because they are irregular and largely healed by quartz. The irregular walls of the fractures were due to the fact that the fractures formed largely by the spreading apart of the constituent grains rather than by breaks through the grains. The grains acted as seed crystals for quartz growth into the fracture openings. This quartz could readily be mistaken for normal sedimentary quartz and thus the fractures could easily be overlooked.

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FACTORS CONTROLLING POROSITY

Many of the siltstones and sandstones initially had good porosity. Although the siltstones typically were rich in phyllosilicates, these phyllosilicates were not in the matrix but were constituents of rock grains mainly slates and schists. Much of the porosity in these siltstones was lost by compaction facilitated by the yielding of these ductile grains and mica flakes. In the more sandy specimens, compaction was aided by moderate pressure solution at quartz contacts. In the clean sands, porosity was lost mainly by secondary quartz cement. Where hydrocarbon entered early, porosity was maintained by the hydrocarbons preventing quartz growth. These hydrocarbons are now solid "fossil" hydrocarbons in the outcrop specimens. If some of the hydrocarbons had been converted to solid form below the surface, they could have acted as seals to prevent loss of later hydrocarbons.

Two types of secondary porosity occur in some of the specimens. One type resulted from partial dissolution of feldspar. Some of the voids are within the grains and did not contribute to effective porosity. In the more advanced dissolutions, outer portions of the grains were removed and the resulting voids were more readily linked to the interstitial pore system. The second type of porosity resulted from fracturing and increased both porosity and permeability. The smaller fractures tended to be filled with quartz or calcite. As mentioned earlier, special care is required to detect these fractures. The fractures with larger openings as at 1604' were not completely filled and could serve as important channelways.

The factors which affected porosity in these specimens would also be important in controlling porosity in subsurface reservoirs.

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REFERENCES

Cheema, Mujeeb, 1977, Sedimentation and gas production of the upper Devonian Benson sand in north-central West Virginia. PhD Dissertation, West Virginia University. 117 p.