Geophys. J. Int. (1992) **108,** 683–691

#/50

A study of two mid-crustal bright spots from southeast Georgia (USA)

Arthur E. Barnes* and Timothy J. Reston†

Institute for the Study of the Continents (INSTOC) and Department of Geological Sciences, Cornell University, Ithaca, New York 14850, *USA*

Accepted 1991 July 29. Received 1991 June 25; in original form 1990 May 21

SUMMARY

Two high-amplitude reflections, or 'bright spots', occur on COCORP (Consortium for Continental Reflection Profiling) line Georgia 16 at a record time of 5.9 s, corresponding to nearly 16 km depth. They are significant because bright spots often mark great contrasts in subsurface physical properties. The first is the 'Surrency Bright Spot' (SBS), an exceptionally bright antiformal reflection, and the second is the 'Reedy Creek Reflection' (RCR), which lies 5 km to the south and resembles the south half of a diffraction. The RCR is also imaged on a crossline, Georgia 18, as a relatively symmetric antiformal reflection. These reflections coincide with the Brunswick magnetic anomaly, thought to mark the late Palaeozoic Alleghanian suture.

The SBS and the RCR are reflections from bodies that lie within the plane of Georgia 16. Migration and 2-D seismic modelling show the aniformal SBS is from a synformal reflector with a buried focus while the RCR is from a relatively small body. The inferred geometry of the SBS reflector, with its flat portion corresponding to the deepest part of the reflector, argues that it does not represent fluids. These results, combined with recent evidence that the SBS is a reflection from a high-velocity thin layer, suggest that the SBS and the RCR might be reflections from ultramafic slices emplaced within the Alleghanian suture zone during collision or from mafic sheets intruded into the suture zone during subsequent rifting. The brightness of the SBS is attributed to a large impedance contrast, constructive interference, good data quality, and a relatively large reflector size with respect to the Fresnel zone and neighbouring reflectors.

Key words: Alleghanian suture, amplitude, bright spots, mid-crust, modelling, seismic reflection.

INTRODUCTION

In early 1985, COCORP completed a seismic reflection survey across the coastal plain of eastern Georgia to explore the presumed late Palaeozoic Alleghanian suture between North America and Africa, thought to be marked by the broad Brunswick magnetic anomaly (Daniels, Zietz & Popenoe 1983; Chowns & Williams 1983; McBride & Nelson 1988; see Fig. 1). This survey discovered several 'bright spots' in the mid-crust (Figs 2, 3, and 4). A bright spot is any unusually high-amplitude seismic reflection (e.g., Coffeen 1978, p. 208; Sheriff 1984), and often indicates a great contrast in the physical properties of adjacent rocks.

Included among these deep bright spots is one that may qualify as the brightest basement reflection yet recorded by COCORP (see the comparison in Fig. 5). This reflection is imaged on line Georgia 16 at 5.9 s record time, about 15.9 km depth, at a point close to the town of Surrency in southern Georgia; it has been dubbed the 'Surrency Bright Spot' (SBS) (Wille 1987). 5 km south another strong reflection is imaged (Figs 2 and 3), referred to here as the 'Reedy Creek Reflection' (RCR). It is also imaged by the crossline Georgia 18 (Fig. 4), providing control on its 3-D geometry.

We carefully examine these bright reflections with the available seismic data. We conclude that the geometry of the SBS makes it unlikely to be a reflection from fluids, and that it and the RCR are reflections from localized south-dipping thin bodies. We interpret these as mafic or ultramafic sheets emplaced in the suture zone during collision or intruded during subsequent rifting.

* Present address: Génie Minéral, École Polytechnique, C.P. 6079, Succursale 'A', Montréal, Québec H3C 3A7, Canada.

† Present address: GEOMAR, 1–3 Wischofstr., D2300, Kiel 14, Germany.

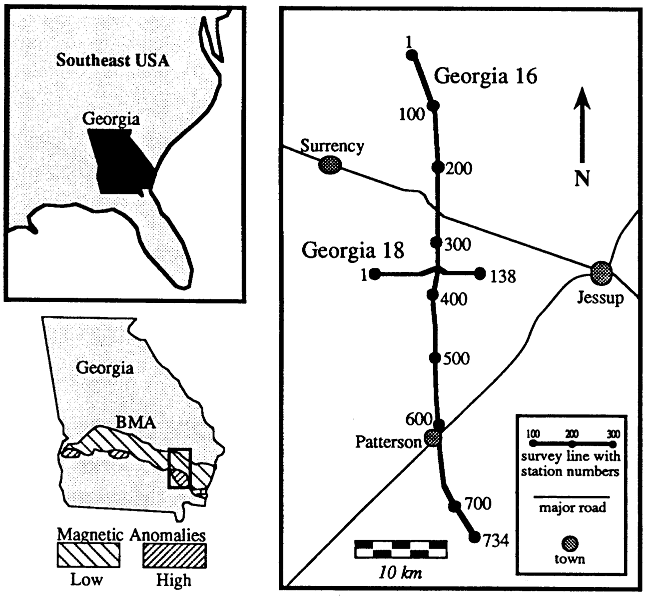


Figure 1. Location map of COCORP lines Georgia 16 and Georgia 18 showing nearby towns and the spatial relationship with the Brunswick magnetic anomaly. Magnetic anomaly patterns after Daniel *et al.* (1983).

SEISMIC DATA

Acquisition and processing

In late 1984 and early 1985, COCORP recorded seismic reflection lines Georgia 16 and Georgia 18, employing vibroseis with an 8 to 32 Hz upsweep for Georgia 16 and a 10 to 32 Hz upsweep for Georgia 18. They were recorded on 96 channels with a 100 m spacing for both source and receiver stations; the nominal common mid-point (CMP) stack fold is 48. On Georgia 16 the receivers were deployed in split-spread geometry with a near offset of 200 m and a far offset of 4900 m. These offsets were chosen shorter than COCORP's typical offset range (0–10 km) to better image relatively shallow buried Triassic basins. For most of Georgia 18 the receivers were fixed while the source moved. The offsets vary from 0 to 9500 m but are between 0 and 5000 m in the centre of the line. There are few skips and the lines are fairly straight (Fig. 1). We employed standard processing to create stacked sections for both lines (e.g. Coffeen 1978, p. 127).

Description

The Surrency bright spot is an asymmetric convex-up mid-crustal reflection 5 km long with abrupt truncations and

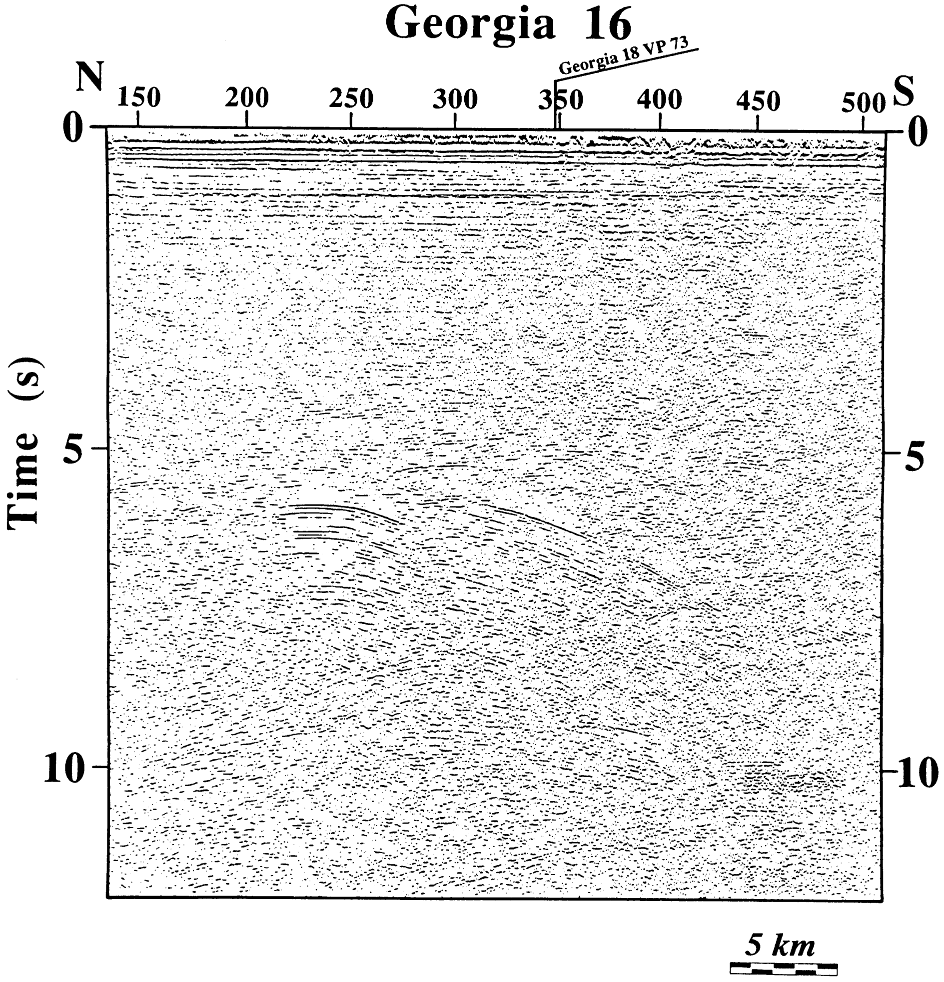


Figure 2. Northern half of Georgia 16 conventionally processed. The high-amplitude reflections of this study are at about 6 s.

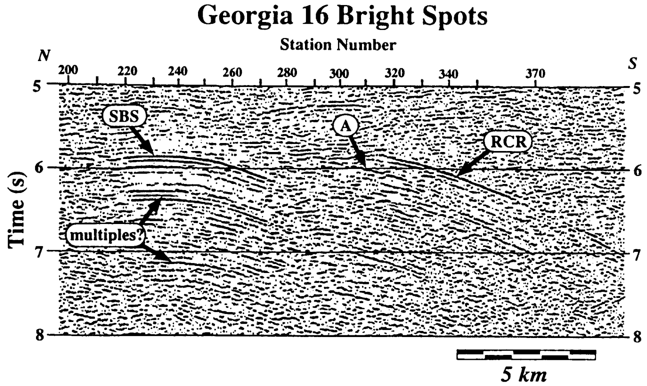


Figure 3. Enlarged portion of Georgia 16 showing the Surrency Bright Spot (SBS) and the Reedy Creek Reflection (RCR). A third mid-crustal primary reflection is noted as 'A'.

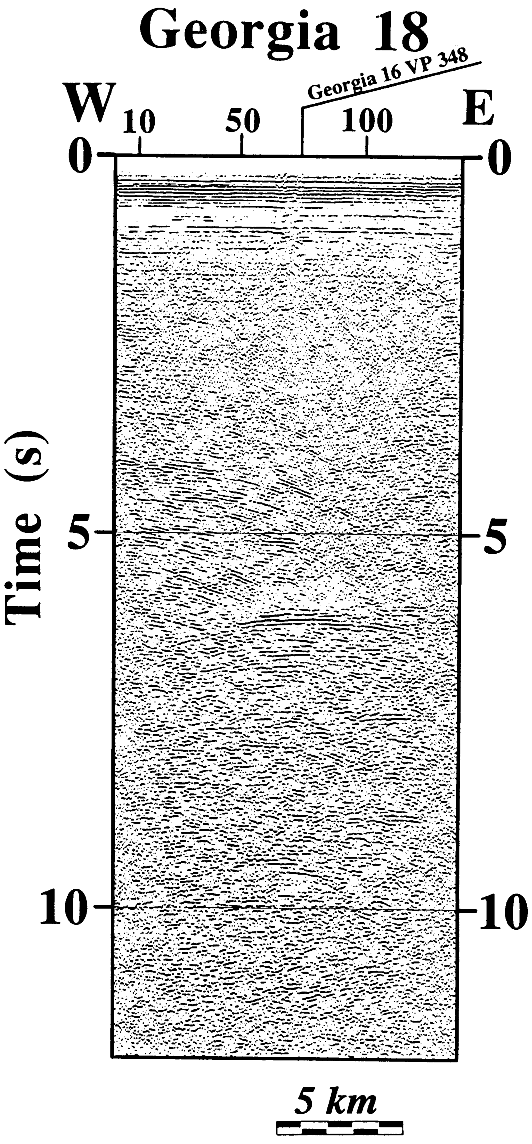


Figure 4. Georgia 18 conventionally processed. The RCR appears on this line as a bright diffraction-like reflection, whose apex at 6.1 s is close to the intersection with Georgia 16; it comes from a body that lies nearly within the plane of Georgia 16.

a 1 km flat top. Its amplitude is enormous—20 dB above background levels (Fig. 5). The neighbouring Reedy Creek reflection is roughly half as bright as the SBS and is imaged on Georgia 16 as a south-dipping, slightly convex-up reflection, and on the crossline, Georgia 18, as a bright convex-up reflection close to the intersection with Georgia 16 (Fig. 4). Hence, the RCR is a reflection from a body that lies nearly within the plane of Georgia 16. Many similar-looking events occur on both lines in the mid- to lower crust, including event 'A' in Fig. 3, and the SBS and RCR are not unusual except that they are bright and appear to be followed by prominent multiples. Semblance velocity analyses (e.g. Yilmaz 1987, p. 173; Waters 1987, p. 304) show the bright spots as well-developed 'bull's-eyes' (Fig. 6), which means they stack in very well, partly accounting for their high amplitude on the stacked sections.

The data are plagued with numerous peg-leg multiple reflections of various periods (Sheriff 1984), probably generated within the sedimentary section between the surface and high-velocity rocks that produce reflections from about 0.2 to 0.6 s. These multiples are particularly apparent on semblance velocity analysis (Fig. 6) and on raw shot files (Fig. 7). The SBS and the RCR are each followed by a train of parallel reflections that fades away with record time (see Figs 3, 6 and 7); beneath the RCR, these give the appearance of an arcuate south-dipping layered reflection sequence. On the basis of this character, and because they have slower stacking velocities than their presumed primary reflections (Fig. 6), we interpret these parallel reflections to be multiples.

The SBS has previously been interpreted as a reflection from a fluid–fluid contact on the basis of on an analogy with 'flat spots' seen on oil industry seismic data from sedimentary basins (Brown 1987; Wille 1987). Flat spots are reflections, often bright, from a contact between two trapped and gravitationally separated fluids, such as gas and water, and are used by the oil industry as so-called 'direct hydrocarbon indicators' (Backus & Chen 1975; Coffeen 1978, p. 208; Lindseth 1982, p. 9.4; Sheriff 1984; Dobrin & Savit 1988, p. 15). However, we maintain that the Surrency bright spots does *not* resemble an oil industry flat spot anomaly and therefore the argument that the SBS might be a reflection from a fluid–fluid contact should not be made on this basis. A flat spot anomaly found on seismic data from a sedimentary basin is a distinct reflection anomalous not just because it is more or less flat but also because it is not conformable with any other reflections. The flat part of the SBS is conformable with the remainder of the reflection. Further, if a flat spot is truly a reflection from a fluid–fluid contact, then it necessarily occurs beneath the reflection from the top of the fluid trap. Such a reflection represents geologic structure, typically has large amplitude, and may itself be a bright spot. No reflection, bright or otherwise, is evident above the SBS that might represent a fluid trap.

ANALYSIS AND RESULTS

Migration

The migration velocities suggested by diffractive events in the mid-crust on both Georgia 16 and Georgia 18 are about 5.4 km s^{-1}. Simple 3-D modelling of the RCR as a reflection from a small body 1 km in diameter embedded in a

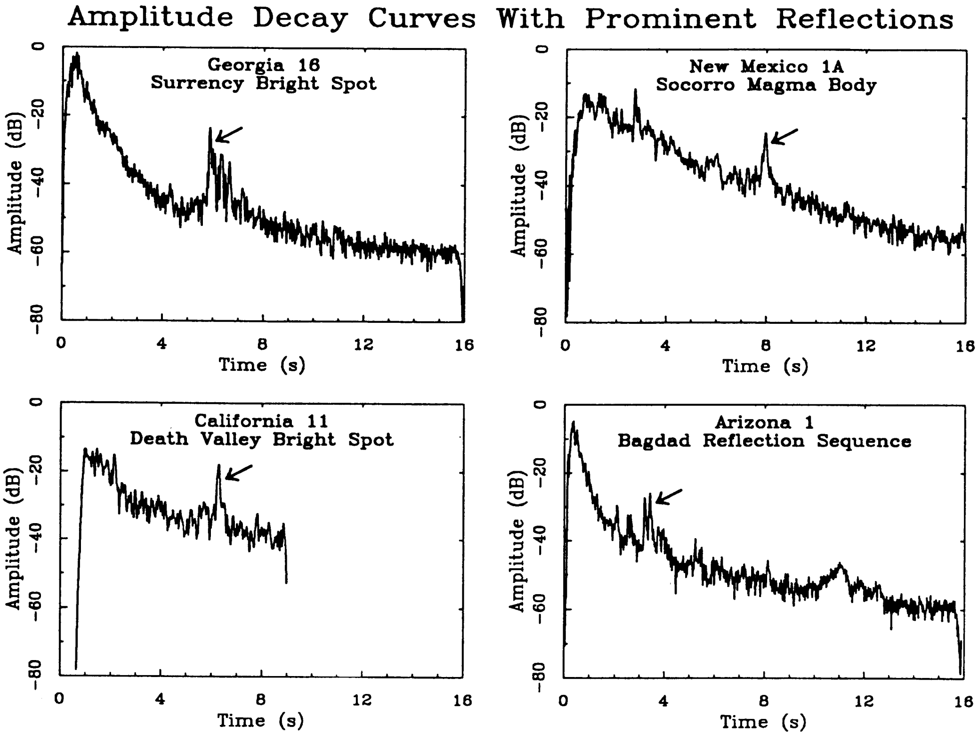


Figure 5. Comparison of amplitude decay for four especially bright events from the COCORP data set; the Surrency bright spot is the brightest in terms of decibels above mean background amplitude. These curves were derived from true amplitude stacks.

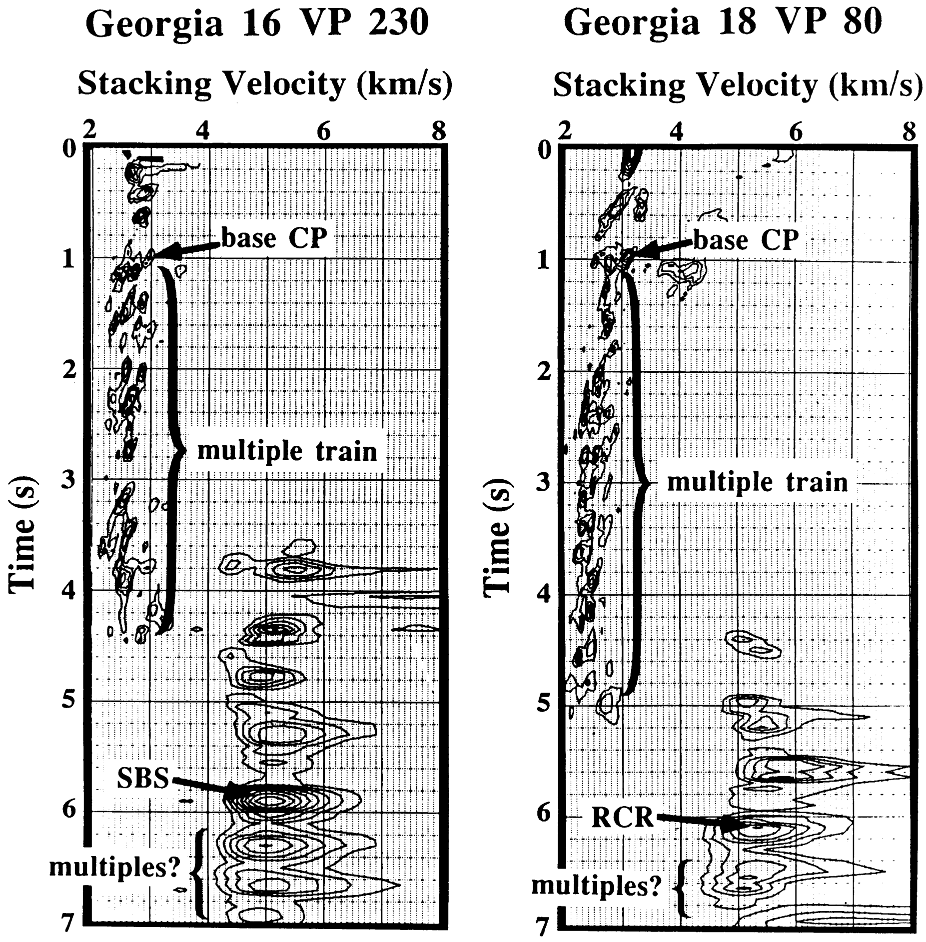
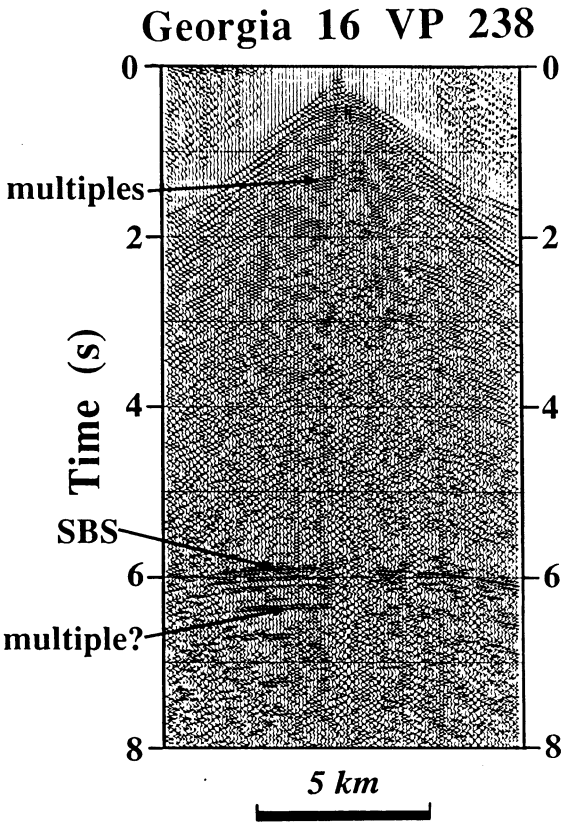


Figure 6. Semblance velocity analysis for Georgia 16 over the Surrency Bright Spot and Georgia 18 over the Reedy Creek reflection. 'CP' is the coastal plain sedimentary sequence. Multiple energy dominates the upper crust below the sedimentary cover.



igure 7. A typical shot record from Georgia 16 showing the SBS nd peg-leg multiples. The base of the coastal plain sedimentary equence lies at 1 s.

omogeneous earth supports this (Fig. 8) and places the entre of the top of this body at a depth of 15.9 km, 0.9 km ast of Georgia 16 and 5.4 km north of Georgia 18; here mall' is with respect to the relevant Fresnel zone radius, hich at the depth of the SBS is 1.6 km for 20 Hz (Sheriff 984). The SBS has a higher rate of curvature than other eflections, yielding an apparent migration velocity of .0 km s^{-1} if it is treated as a diffraction (Fig. 8). Since the esults of a recent survey indicate that the SBS appears to be early from within the plane of Georgia 16 (Pratt *et al.* 991), and therefore it is not side-scattered energy that has ravelled through shallow low-velocity rock, we conclude it not a partially imaged diffraction from a small body.

To better determine the geometry of the reflecting tructure, we migrated Georgia 16. This was done for arious constant velocities; that portion of the migrated ections containing the SBS and RCR is shown in Fig. 9 for elocities of 4.8, 5.4 and 6 km s^{-1}. We prefer the 5.4 km s^{-1} igration as it looks the 'most reasonable', and because it is onsistent with the migration velocity estimates obtained rom the diffractive events. However, as the three igrations are similar, and all show the SBS as a synformal eflection, our interpretation will not be greatly dependent n the exact migration velocity chosen. We interpret the igration as showing that the SBS is a reflection from a ynformal reflector whose focus is buried beneath the urface (e.g. Sheriff 1984, p. 26). The curvature of a eflection from such a 'buried focus reflector' is approximtely that of a diffraction located at the depth of the focus and so is always greater than that of a diffraction from a small body at the same depth. The long curving RCR migrates to a small south-dipping reflection at about 5.8 s, which flattens upwards slightly above the flattest, deepest portion of the SBS.

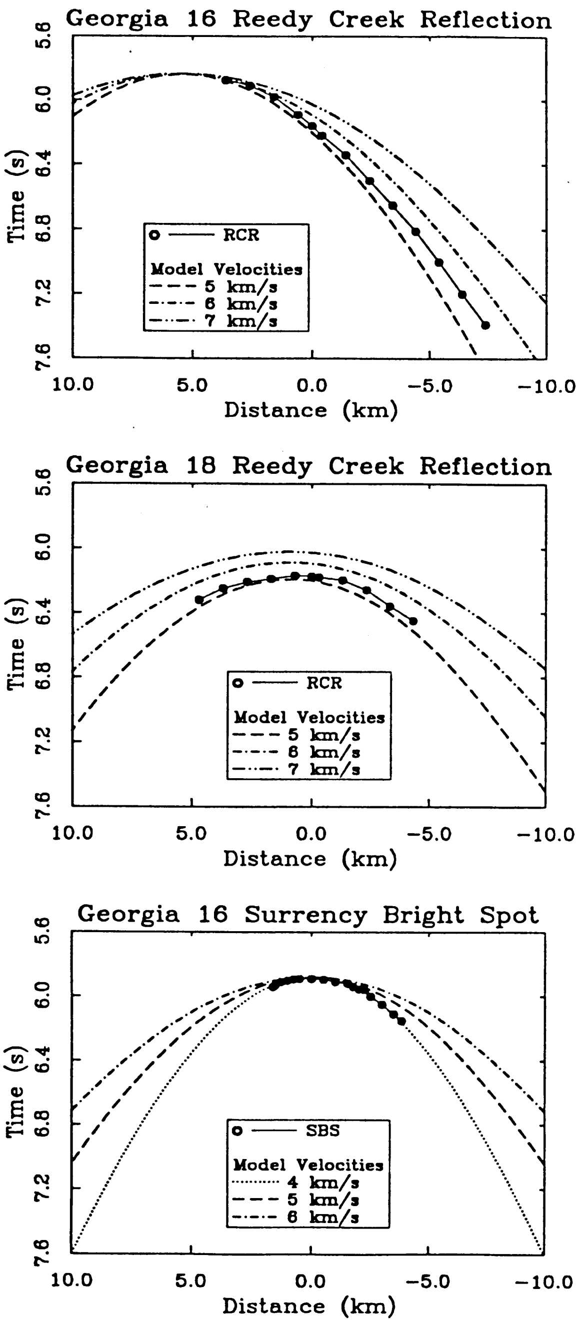


Figure 8. Arrival times of the RCR and SBS compared with theoretical arrival times for reflections from spheres of 1 km diameter. For the RCR this suggests an average migration velocity of 5.4 km s^{-1}, which is reasonable. In contrast, the SBS gives an unreasonable migration velocity of about 4.0 km s^{-1}; the great curvature of the SBS cannot be explained as due to diffraction.

Modelling

Seismic modelling with GeoQuest's AIMS® provides further evidence that the SBS is from a synformal reflector

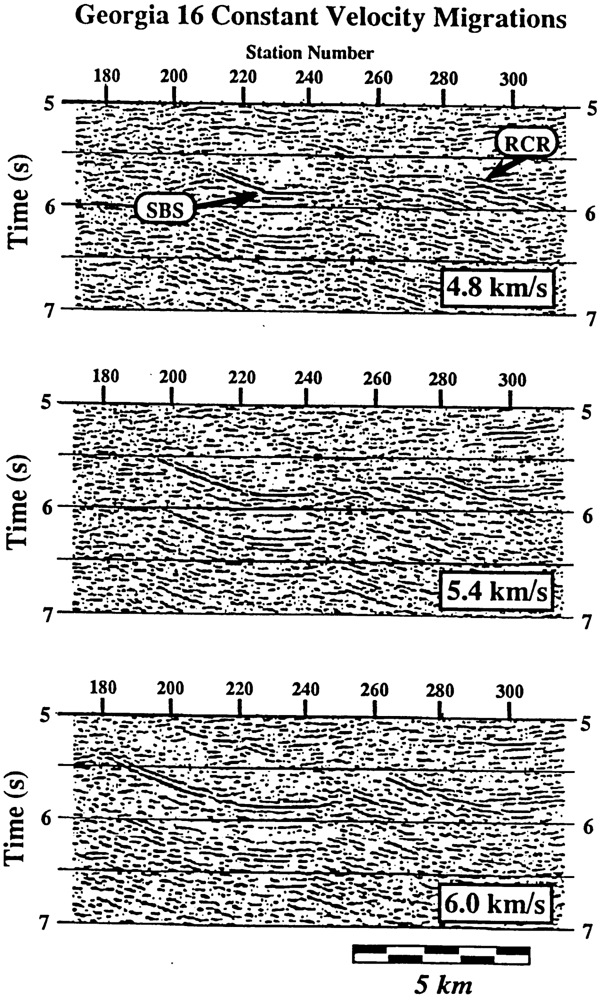


Figure 9. Constant velocity wave-equation migrations of the Surrency bright spot at 4.8, 5.4, and 6.0 km s^{-1}. While we prefer the 5.4 km s^{-1} migration because it looks 'most reasonable', the exact migration velocity used does not greatly affect our interpretation.

with a buried focus, and the long dipping RCR is generated from a small body in the mid-crust. We model the reflectors as thin sheets up to 80 m thick whose position and geometry match the migrated position of the bright spots (Fig. 10a). 80 m is the thickness we estimated for the SBS reflector by waveform modelling, assuming that it is an isolated thin body, estimating the spectrum of the source wavelet directly from the data, and assuming zero-phase data; this is reasonably consistent with the arguably more reliable estimate of 120 m given by Pratt *et al.* (1991). These sheets are assigned a velocity and density of 7.5 km s^{-1} and 3.2 g cm^{-3} respectively and are set in a crust of velocity 6 km s^{-1} and density 2.7 g cm^{-3}. This is overlain by a 1.4 km thick veneer, representing the Coastal Plain sedimentary sequence, with velocity 2 km s^{-1} at the surface increasing to 4 km s^{-1} at depth. The velocity values are in general agreement with those derived from stacking velocity analysis. We model the SBS reflector as a high-velocity body to be consistent with the findings of Pratt *et al.*; this does not affect the geometry of the results, but only the polarity, which is ambiguous for our data. The precise values of velocity and density employed are unimportant as absolute reflection coefficients cannot be reliably determined from our data.

A wave theory approximation (Kirchhoff) was used to generate the synthetic seismic response of this model: a synthetic spike section is constructed by summing diffraction rays from closely spaced points on each reflecting surface. Unlike normal incidence ray tracing, this method automatically generates diffractions and has the advantage of accurately handling the amplitude of reflections from a buried focus, though multiples cannot be modelled. Random noise was added to the synthetic spike section with an average amplitude 20 dB down from the peak amplitude on the profile, similar to the observed amplitude contrast between the bright spot and background energy (Fig. 5). The synthetic section was then convolved with an 8–32 Hz zero-phase Klauder wavelet to be comparable to the vibroseis data. To further simulate real seismic data, a 1-2-1 weighted running mix was performed to approximate the effects of source and receiver arrays and stacking, which act as dip filters. The resulting synthetic section is given in Fig. 10(b). The synthetic reflections correspond well in geometry and character to the SBS, RCR, and the 'A' reflection (compare with Fig. 3).

The model of Fig. 10(a) has a number of consequences for the interpretation. First, the synformal geometry of the SBS reflector has probably not significantly increased the amplitude of the SBS by focusing. Second, its great length relative to the Fresnel zone ensures that for identical impedance contrasts it will nonetheless have greater amplitude than reflectors that are small with respect to the Fresnel zone, such as the RCR and the 'A'. Many deep crustal reflections are thought to come from small structures (Hurich & Smithson 1987; Reston 1987) that scatter seismic energy to produce diffraction-like reflections whose amplitude is a function of relative size (Sheriff & Geldart 1982; Raynaud 1988, p. 121). That the amplitude of the RCR is half that of the SBS can thus be explained by differences in reflector size without invoking different lithologies. Third, given the model, the observed amplitude spectrum of our data, and assuming zero-phase, we calculate that constructive interference between wavelets reflected off the top and the bottom of this sheet produces a composite wavelet with a 50 per cent increase in peak amplitude over that of the single wavelet from the top of the sheet; this might be another factor causing the relative brightness of the SBS. Fourth, as the migration and modelling both suggest that the flat top of the SBS is a reflection from the *deepest* part of a synformal structure, it is unlikely to represent either a fluid–fluid contact or the top of trapped fluid. Fifth, whereas the RCR and its train or parallel reflections were previously interpreted as deep-rooting imbricate thrust faults associated with the suture (e.g. Wille 1987; McBride & Nelson 1988), our results argue that the RCR actually comes from a small mid-crustal body and the parallel reflections are peg-leg multiples.

GEOLOGICAL INTERPRETATION

The similarities and proximity of the Surrency bright spot and the Reedy Creek reflection lead us to interpret them as genetically related. The SBS and RCR might be reflections

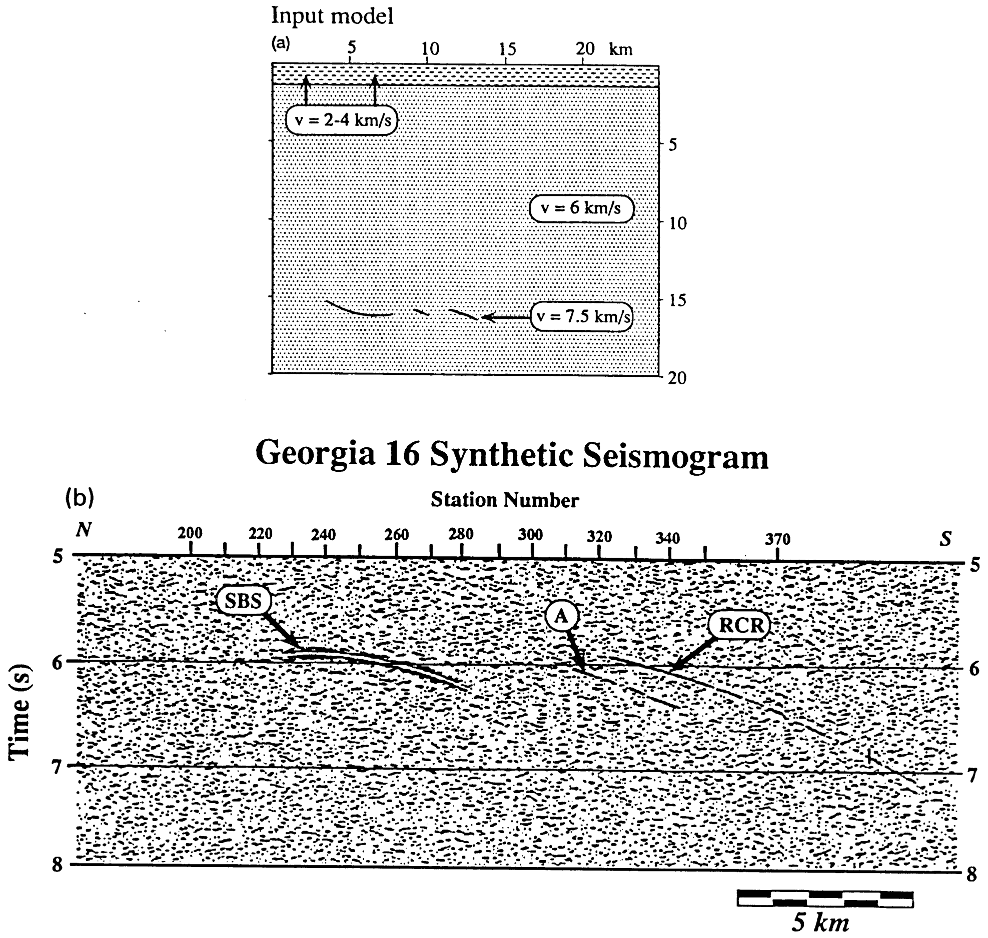


Figure 10. AIMS® modelling. (a) Input model, consisting of high-velocity thin sheets in the mid-crust. (b) Derived synthetic seismogram. The reflection from the synformal reflector matches well the shape, amplitude and appearance of the SBS, and the two small bodies produce broad diffractive events that match the RCR and the 'A'. Compare with Fig. 3.

from deep crustal or mantle rocks entrained along the suture during the late Palaeozoic collision that formed the Alleghanian suture. Sharp contacts between ultramafic rocks, such as pyroxenites or lherzolites, and crustal rocks, such as tonalitic or granitic gneisses, can provide reflection coefficients of 0.2 (e.g. Hurich & Smithson 1987), twice that determined for bright intracrustal reflections observed offshore Britain (Warner 1990), which could explain the anomalously bright reflections described here. This is consistent with the tectonic setting: ultramafic lenses and slices of the lower crust (e.g. the Ivrea Zone) are found along the Alpine suture (the Insubric Line) in northern Italy (e.g. Fountain & Salisbury 1981) and have been interpreted from geophysical data within the Saxothuringian–Moldanubian suture in the Oberpfalz region of Bavaria (DEKORP Research Group 1987).

The SBS and RCR could also be reflections from slices of obducted oceanic crust, dismembered and smeared within the suture zone during final collision and generated at the sheared contact between mafic (oceanic) and more felsic (continental) lithologies. Such contacts can produce strong reflections, but probably not as strong as those involving ultramafic and felsic rocks.

Alternatively, the SBS and RCR could be reflections from mafic bodies intruded during subsequent Jurassic rifting. During the Jurassic, massive amounts of basalt and diabase were extruded in southeast Georgia (McBride, Nelson & Brown 1989), and in northern Georgia and southwest South Carolina the upper crust is shot full of numerous diabase dikes of late Triassic and Jurassic age (Daniels *et al.* 1983). Daniels *et al.* (1983) further suggest that diabase dikes of similar origin extend beneath the coastal plain of southern Georgia but are too deep to be resolved by magnetic data. Such dikes could well be the source of the SBS and the RCR and of the many diffractions observed on lines Georgia 16 and Georgia 18; the SBS and RCR are brighter than the others perhaps only because of geometry and greater size. If the reflectors are mafic intrusions, it is possible they are unrelated to the suture. It is also possible that they were intruded along a thrust fault associated with the suture that formed a zone of pre-existing weakness, though the fault is not otherwise imaged. They could occur at bends in a ramp–flat–ramp and duplex structure where the rock is fractured or weakened, as such zones seem likely sites for large igneous intrusions.

Figure 11 is a speculative geologic interpretation of Georgia 16: the Surrency reflector and the Reedy Creek reflector are the largest and most prominent of many mafic

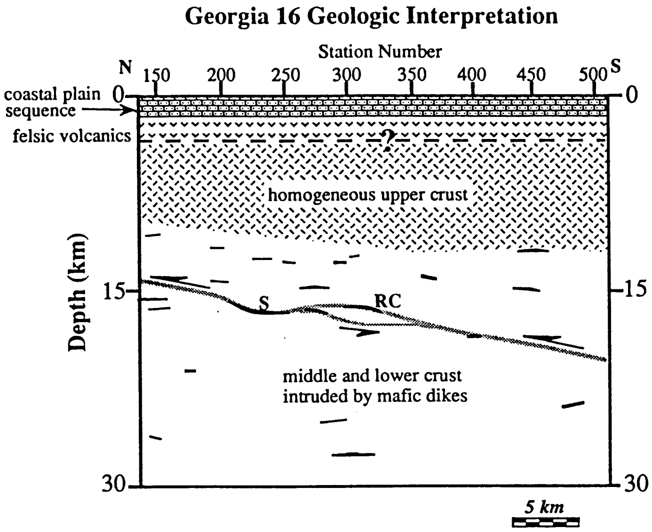


Figure 11. A speculative geologic interpretation of Georgia 16: the Surrency reflector (S) and the Reedy Creek reflector (RC) are the largest and most prominent of many mafic intrusions in the mid- and lower crust and are intruded into a ramp–flat–ramp and duplex structure along a crustal scale thrust fault associated with the Alleghanian suture, which, however, is not directly imaged.

intrusions in the mid- and lower crust and are intruded into a ramp–flat–ramp and duplex structure along a crustal scale thrust fault associated with the Alleghanian suture. The thrust fault is included in the interpretation because of the geologic setting and because as a zone of weakness it could be expected to accommodate relatively larger intrusions, thereby explaining the relatively greater size of the SBS and RCR reflectors; the data do not otherwise provide evidence for the existence of major faults.

Other mid-crustal bright spots identified on the COCORP data set have been interpreted as mafic intrusions (e.g. Brown 1987). However, the contact between a mafic intrusion and a crustal rock does not provide as significant a reflection coefficient (a value of about 0.1 is often quoted—e.g. Hurich & Smithson 1987) as that between the same crustal rock and an ultramafic body from the mantle.

CONCLUSIONS

Two neighbouring anomalously high-amplitude mid-crustal reflections are imaged on COCORP lines Georgia 16 and Georgia 18; these are called the Surrency bright spot and the Reedy Creek reflection. They resemble partial diffractions on Georgia 16, and the RCR resembles a fairly complete diffraction on the crossline, Georgia 18. The RCR reflector lies within the plane of Georgia 16. Independent evidence suggests the SBS also lies within the plane of Georgia 16 and might be a composite reflection from a high-velocity thin layer of roughly 80 m thickness.

The SBS appears to be a reflection from a high-velocity synformal reflector with a buried focus. The flat top of the unmigrated SBS corresponds to the *deepest* portion of the reflector and so is unlikely to represent either a fluid–fluid contact or the top of fluids trapped in the mid-crust.

The Surrency bright spot and the Reedy Creek reflection might be parts of a single incompletely imaged structure. The association between the bright spots and the suture zone suggests that the reflectors could be small bodies trapped or emplaced along faults within the suture zone. They might be lenses or sheets of mafic or ultramafic material from the lowermost crust or mantle that were entrained within the suture during thrusting or they could be fragments of oceanic crust obducted prior to collision or mafic intrusions locally emplaced within a weak suture zone during subsequent rifting.

The SBS and the RCR are not unusual except that the SBS is extraordinarily bright. The relative brightness of the SBS we attribute to four factors: a high impedance contrast, thin bed constructive inference, good-quality data, and a relatively large size and synformal geometry that, in marked contrast with its smaller neighbours, does not widely scatter energy and thereby diminish its amplitude.

ACKNOWLEDGMENTS

Discussions with Bob Litak, Tom Chaimov, Tom Pratt, Tom Hearn, Doug Nelson, Terry Jordan, and Ray Culotta helped refine our arguments. Larry Brown critically reviewed the manuscript. Steve Gallow's technical assistance was invaluable. Two-dimensional modelling was done with the AIMS® modelling package. This work was supported by National Science Foundation grants EAR-84-18157 and EAR-86-09992 (AEB), and by NATO fellowship GT8/F/87/GS/1 (TJR). INSTOC contribution 141.

REFERENCES

Backus, M. M. & Chen, R. L., 1975. Flat spot exploration, *Geophys. Prosp.*, **23,** 533–577.

Brown, L. D., 1987. Lower continental crust: Variations mapped by COCORP deep seismic profiling, *Annales Geophysicae,* **5B,** 325–330.

Chowns, T. M. & Williams, C. T., 1983. Pre-Cretaceous rocks beneath the Georgia coastal plain—Regional implications, in *Studies Related to the Charleston, South Carolina Earthquake of 1886—Tectonics and Seismicity,* pp. L1–L42, ed. Gohn, G., United States Geological Survey Professional Paper 1313, Boulder, CO.

Coffeen, J. A., 1978. *Seismic Exploration Fundamentals,* PennWell Books, Tulsa, OK.

Daniels, D. L., Zietz, I. & Popenoe, P., 1983. Distribution of subsurface lower Mesozoic rocks in the southeastern United States, as interpreted from regional aeromagnetic and gravity maps, in *Studies Related to the Charleston, South Carolina Earthquake of 1886—Tectonics and Seismicity,* pp. K1–K24, ed. Gohn, G., United States Geological Survey Professional Paper 1313, Boulder, CO.

DEKORP Rearch Group, 1987. Results of deep reflection seismic profiling in the Oberpfalz (Bavaria), *Geophys. J. R. astr. Soc.,* **89,** 353–360.

Dobrin, M. H. & Savit, C. H., 1988. *Introduction to Geophysical Prospecting,* McGraw-Hill, New York.

Fountain, D. & Salisbury, M., 1981. Exposed cross-sections through the continental crust: Implications for crustal structure, petrology and evolution, *Earth planet. Sci. Lett.,* **56,** 263–277.

Hurich, C. & Smithson, S., 1987. Compositional variation and the origin of deep crustal reflections, *Earth planet. Sci. Lett.,* **85,** 416–426.

Lindseth, R. O., 1982. *Digital Processing of Geophysical Data: A Review,* Society of Exploration Geophysicists, Tulsa, OK.

McBride, J. H. & Nelson, K. D., 1988. Integration of COCORP deep reflection and magnetic anomaly analysis in the southeastern United States: Implications for origin of the Brunswick and East Coast magnetic anomalies, *Geol. Soc. Am. Bull.*, **100,** 436–445.

McBride, J. H., Nelson, K. D. & Brown, L. D., 1989. Evidence and implications of an extensive early Mesozoic rift basin and basalt/diabase sequence beneath the southeast Coastal Plain, *Geol. Soc. Am. Bull.*, **101,** 512–520.

Pratt, T. L., Hauser, E. C., Hearn, T. M. & Reston, T. J., 1991. Reflection polarity of the mid-crustal Surrency Bright Spot beneath southeastern Georgia: Testing the fluid hypothesis, *J. geophys. Res.*, **96,** 10 145–10 158.

Raynaud, B., 1988. Diffraction modelling of 3-D lower crustal reflectors, *Geophys. J.*, **93,** 149–161.

Reston, T. J., 1987. Spatial interference, reflection character and the 3-D structure of the lower crust under extension: Results from 2-D seismic modelling, *Annales Geophysicae,* **5B,** 339–348.

Sheriff, R. E., 1984. *Encylopedic Dictionary of Exploration Geophysics,* Society of Exploration Geophysicists, Tulsa, OK.

Sheriff, R. E. & Geldart, L. P., 1982. *Exploration Seismology, Volume 1: History, Theory and Data Acquisition,* Cambridge University Press, Cambridge, UK.

Warner, M., 1990. Absolute reflection coefficients from deep seismic reflections, *Tectonophysics,* **173,** 15–23.

Waters, K. H., 1987. *Reflection Seismology: A Tool for Energy Resource Exploration,* Wiley, New York.

Wille, D. M., 1987. The COCORP Surrency Bright Spot: Possible evidence for fluid in the deep crust, *MSc thesis,* Cornell University.

Yilmaz, O., 1987. *Seismic Data Processing,* Society of Exploration Geophysicists, Tulsa, OK.